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CLASSIFICATION METHODS FOR INLAND EXCESS WATER MODELING

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Abstract
Inland excess water floodings are a common problem in the Carpathian Basin. Nearly every year large areas are covered by water due to lack of natural runoff of superfluous water. To study the development of this phenomenon it is necessary to determine where these inundations are occurring. This research evaluates different methods to classify inland excess water occurrences on a study area covering south-east Hungary and northern Serbia. The region is susceptible to this type of flooding due to its geographical circumstances. Three separate methods are used to determine their applicability to the problem. The methods use the same input data set but differ in approach and complexity. The input data set consists of a mosaic of RapidEye medium resolution satellite images. The results of the classifications show that all three methods can be applied to the problem and provide high quality satellite based inland excess water maps over a large area.

Keywords: classification, inland excess water, spectral mixture analysis, artificial neural network

INTRODUCTION

The year 2010 was one of the wettest years ever on the Carpathian Basin. In Szeged, almost twice as much precipitation fell as the long term yearly average (Van Leeuwen et al., 2012). This caused exceptionally large areas to be flooded by water. This phenomenon where water remains temporary in local depression because of a surplus of water due to lack of runoff, insufficient evaporation and low infiltration capacity of the soil or due to upwelling of ground water is called inland excess water. Factors that determine the sensitivity of an area to inland excess water are among others meteorology, relief, soil, groundwater, and human influences like land use and the construction of water works (Pálfai, 2004). Inland excess water damages crops, obstructs agricultural activities and local transportation, leads to soil and groundwater contamination and deterioration of the soil quality in the long term. In the border region of Hungary and Serbia, the natural circumstances are such that the area is vulnerable to inland excess water.

Different methods have been developed to determine the extent and location of inland excess water. Before the development of remote sensing techniques, the inundations could only be measured by observation in the field. This methods is expensive, time consuming and inaccurate. Visual interpretation of aerial photographs of inundated areas reduced the time needed to identify the floodings and reduced the inaccuracy but is expensive. This study uses (semi-) automatic classification methods to determine the occurrences of inland excess water based on satellite images. Provided that their resolution is high enough, satellite image classification can yield accurate results and is less expensive than traditional methods.

STUDY AREA

The study area is located in the cross border area between south-east Hungary and northern Serbia, covering 1600 km^2 in the wider surrounding of the towns of Szeged, Kanjiža and Novi Knezevac, extending on both sides of the Tisza River (*Fig. 1*). This relatively flat, and generally low lying territory (between 75 and 150 m) was formed predominantly by fluvial processes, as is illustrated by the abandoned meanders, natural levees, point-bar systems, scour channels and swales of the Maros and Tisza Rivers (Mezősi, 1983; Benyhe and

Kiss 2012), and also partly by eolian processes which shaped the higher geomorphologic units of loess terraces and sands (Bukurov, 1975; Davidović et al., 2003; Košćal et al., 2005).

Fig. 1 Overview map of the Hungarian – Serbian study area

Agriculture is one of the predominant economic activities, which also suffers the most damages due to the inundations. Inland excess water occurs frequently, mostly in low lying zones and also on higher geomorphologic units where local topographical, geological, hydrological and pedological conditions allow the formation of temporary standing surface water.

DATA AND METHODS

For this study, RapidEye satellite images were collected on March 24 and 25 of 2011, during the severe inland excess period of 2010-2011. The individual images were atmospherically corrected and mosaiced together covering an area of 5000 km^2. From the large mosaic, a sub image was created showing an area of about 40 x 40 kilometer (*Fig. 2*). Even after the atmospheric correction, several areas in the mosaic are severely affected by haze. This influences the quality of the classification results.

The RapidEye constellation, launched in 2008, is a system of 5 commercially operated satellites each carrying a 5-band multi-spectral imaging instrument providing daily revisiting time for every location between 84° N and 84° S on the Earth surface (RapidEye, 2012). The instrument acquires images in the spectral range between 440 and 850 nm (*Table 1*) with a spatial resolution of 6.5 meter (resampled to a pixel size of 5 meter) at nadir and a swath width of 77 kilometer. Due to the programmability of the satellites, they are more flexible than other satellites with global coverage like the Landsat satellites.

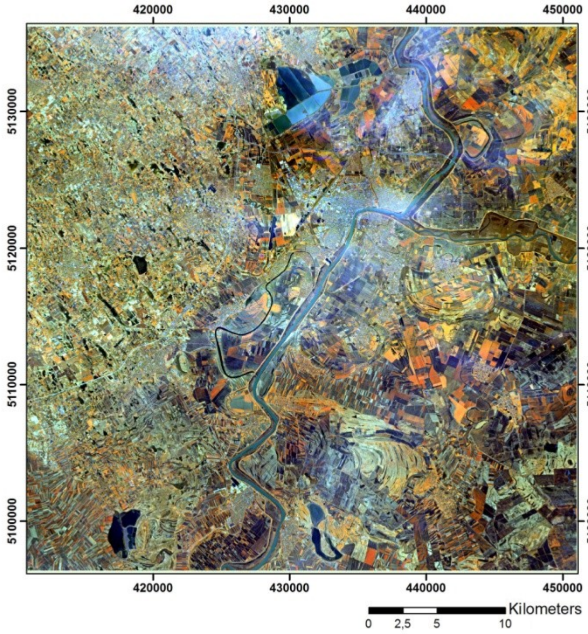

Fig. 2 RapidEye false color composite (bands 5-4-1) of the study area

Table 1 Spectral characteristics of RapidEye images

Band	Name	Spectral range (nm)
1	Blue	440 – 510
2	Green	520 – 590
3	Red	630 – 685
4	Red-Edge	690 – 730
5	Near Infrared	760 – 850

To investigate the best method to identify inland excess water based on remote sensing data, three classifications methods are executed on a RapidEye satellite image using the same training data set. The classification results were compared with areas defined in the training set.

Training data set

A training data set consisting of 8 classes (*Table 2*) was derived by delineating samples using a seed method, where starting from one clear pixel – adjacent, spectrally similar – pixels were selected. In this way, a minimum of spectrally mixed pixels is added to the training data set. Every class is represented by several thousands of pixels. Proper sampling of the intermediate classes like saturated soil and vegetation in water is difficult without fieldwork, and therefore these classes are not included. A "High albedo" class was added to the training class containing very bright pixels.

Table 2 Training classes

	Class name		Class name
1	Inland excess water	5	Vegetation3
2	High albedo	6	Deep water
3	Vegetation1	7	Bare soil
4	Vegetation2	8	Shallow water

Maximum Likelihood

The Maximum likelihood (ML) classification is a commonly used supervised classification technique, which directly uses all bands of the data set to define the statistical relationship between the input and output data. The maximum likelihood classification is a statistical approach where the probability of a pixel belonging to each of the predefined set of classes is calculated, and the pixel is then assigned to the class for which the probability is the highest (Tso and Mather, 2009). The method assumes a multivariate normal (Gaussian) distribution of the classes in the data set. This assumption of normality is generally reasonable for spectral response distributions in satellite imagery (Lillesand et al., 2004). The method is computational intensive because the probability for every class needs to be calculated.

Spectral Mixture Analyses

The aim of Spectral Mixture Analysis (SMA) is to determine the spatial ratio of spectrally homogeneous land cover types, the so-called endmembers, within a pixel. Each endmember specifies an unmixed, pure land cover type. The Linear Spectral Mixture Analysis (LSMA) is an improvement of the SMA method, by which the ratio of land cover types can be determined by using minimum two, and in case of a RapidEye image, maximum five endmembers. To be able to solve the linear system of equations (1), the number of the endmembers has to be less than or equal to the number of the spectral bands of the image.

$$R_b = \sum_{i=1}^{N} f_i \cdot R_{i,b} + \varepsilon_b \qquad (1)$$

R_b: the reflectance value of the image in band b;
N: the number of endmembers;
f_i: the ratio factor of endmember i;
R_{ib}: the reflectance value of the i^{th} endmember in band b;
ε_b: residual error.

The sum of the ratio factors of the endmembers equals 1 in every pixel and $f_i \geq 0$.

$$\sum_{k=1}^{n} f_{i,k} = 1 \qquad (2)$$

The suitability of the model can be determined on the basis of the ε_b residual error or on the basis of the value of the root mean square error (RMSE) for each band of the image.

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n} \varepsilon_i^2}}{n} \qquad (3)$$

There are several techniques to select the endmembers. They can be selected from the different bands of the satellite images or 2 D scatter plots worked out from the bands (Rashed et al., 2001). By Principal Component Analysis (PCA), the endmembers are easier to determine, since it assembles almost 90% of the data variance into the first two or three bands and reduces the correlation between the bands to a minimum (Smith et al., 1985). Another frequently used method is to apply a transformation called the minimum noise fraction (MNF) method. This method consists of two main steps: (1) in the first step the noise fractions of the data set are decorrelated and rescaled on the basis of an estimated noise covariance matrix, resulting in transformed data, of which the noise has unit variance and where there is no correlation between the bands; (2) in the second step a traditional PCA is carried out (Green et al., 1988). In this research, the PCA method was used to determine the endmembers.

In the first step, PCA images were created for the RapidEye image taken on 24th March 2011, which resulted in another 5 bands. The information content of the images is continuously decreasing after one another, thus the first three bands contain 98.9% of the total information content. The last bands predominantly contain noise.

Based on the first three PCA images, three endmembers were defined for the linear spectral mixture: (1) the water surfaces, (2) the vegetation, and (3) the soil. These endmembers were pointed out in the spectral space formed by the first three PCA-bands and were detected at the margins and peaks of the 2D scatter plot. In the created fraction maps, for every single pixel the percentage of one of the three categories is calculated. A pixel value of 1 means that the pixel is homogenous and that it consists of 100% of the specific category. In the final step of the SMA methods, the newly generated 3 band endmember composite is used as input data for a maximum likelihood classification as described above. In the LM classification the same training data set was used as in the other two classification methods.

Artificial neural networks

Artificial neural networks (ANN) are computational models that mimic the functioning of the human brain. They are computational mechanisms that are able to acquire, represent, and compute a mapping from one multivariate space of information to another, given a set of data representing that mapping (Atkinson and Tatnall, 1997). Schematically, a basic artificial neural network can be presented as a structure consisting of multiple layers of interconnected nodes as shown in *Figure 3*.

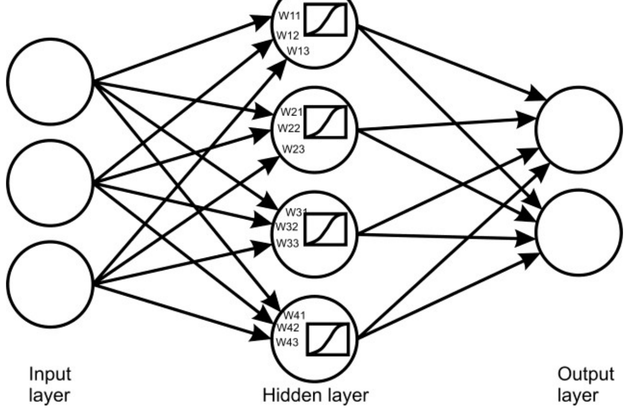

Fig. 3 Basic artificial neural network

Table 3 Cross table showing the training validation of the maximum likelihood classification

Training	ML result								Number of pixels	User Acc
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**		
1	2944	0	0	0	25	1096	0	8	4073	0.72
2	0	3542	0	0	0	0	67	0	3609	0.98
3	0	0	4568	9	0	0	0	0	4577	1.00
4	0	4	133	9774	112	0	3	0	10026	0.97
5	19	0	0	36	5408	0	0	2	5465	0.99
6	995	0	0	0	1	8968	0	0	9964	0.90
7	0	187	0	13	1	0	9489	0	9690	0.98
8	0	0	0	0	0	0	10	8929	8939	1.00
# of pixels	**3958**	**3733**	**4701**	**9832**	**5547**	**10064**	**9569**	**8939**	**56343**	
Prod. Acc.	0.74	0.95	0.97	0.99	0.97	0.89	0.99	1.00		**OA=0.95**

The application of ANNs consists of two phases. The first phase is called the training phase. During this phase the ANN is presented with an input and an associate output data set. The training is a process that aims to adapt the network internally in such a way that the calculated results from the network are as close as possible to the expected results. Iteratively, the internal weights are adapted based on the direction in which the error is moving. When the error is not decreasing anymore, the weights are fixed and the network is stored. Subsequently, the network is used in the simulation phase where the trained network is presented with a new input data set that is similar to the input data set of the training phase. If the network was trained properly and the new input data covers the same problem domain as during the training phase, accurate results can be obtained.

One of the most popular artificial neural models used in pattern classification, prediction and regression tasks is the multilayer perceptron (MLP) (Atkinson and Tatnall, 1997; Demuth et al., 2010; Pradhan et al., 2010). An MLP is the feed forward multilayer network where a signal propagates in a forward manner from one layer to the next layer and is modified by the associated weights of each connection (Pradhan et al., 2010). This means that there is neither direct, nor indirect influence from a given neuron to its own inputs. The network has an input layer, at least one hidden layer and an output layer.

In an MLP, the signal of all input neurons is weighted and summed to a net output. This net output is then evaluated by an activation function where it produces an output. Different activation functions exist but with MLPs usually – and also in this study – log-sigmoid functions are used, which ensure non-linearity to the method.

MLPs are often combined with a backpropagation learning algorithm. The algorithm randomly selects the initial weights for every neuron and then calculates an output based on a set of inputs. The calculated outputs are compared to the expected output and the error is calculated. Subsequently, the weights are adapted based on the errors in such a way that the total error is distributed among the neurons in the network (Yang and Rosenbaum, 2001). To be able to calculate the effect of the change of the individual weights the first derivative of the activation function is needed. This requires that the activation function is differentiable. The process of feeding forward signals and back-propagating the errors via the output layer to the hidden layer is repeated iteratively until some targeted minimal error is achieved between the desired and actual output values of the network (Dawson and Wilby, 2001; Pijanowski et al., 2002, Pradhan et al., 2010). The weights are then stored to retain the knowledge in the network. After training, when presented with an arbitrary input pattern that is noisy or incomplete, the neurons in the hidden layers of the network will respond with an active output, if the new input contains a pattern that resembles the feature the individual neurons learned to recognize during the training (Hagan et al., 1996; Freeman and Skapura, 1991).

To calculated the inland excess water results in this study, a GIS - ANN framework (Van Leeuwen et al., 2012) was used, that is based on ArcGIS, a geographic information system and Matlab, a mathematical modeling software.

RESULTS

Validation is not possible based on ground truth data because it is not possible to collect inland excess water information from such a large area. Therefore internal validation is executed based on the training areas. This means that the results of the classifications are compared with the predefined training sets. In the case of the maximum likelihood and spectral mixture analysis all pixels from the input training set were used to perform the classification, while in case of the artificial neural network classification 70% of the training data was used for actual training and the other 30% was used for testing and validation of the training.

Maximum likelihood

The maximum likelihood classification has an overall accuracy of 0.95 (*Table 3*). The most problematic class is the Inland excess water (1) class with a user accuracy of 0.72. Many pixels are classified as Deep water (6). Obviously when combining these classes and the Shallow water (8) class as well, the results are much better. In this case, both the user and producer accuracy for the combined water class is 0.99. All other classes show very little misclassification.
Visual inspection of the output map reveals large areas covered with water in the east and south east (*Fig. 4*). The large lake systems in the north and along the Tisza River are properly classified. The areas with High albedo (2) are found in the city of Szeged, on the sand soils in the north-west, and in the south center.

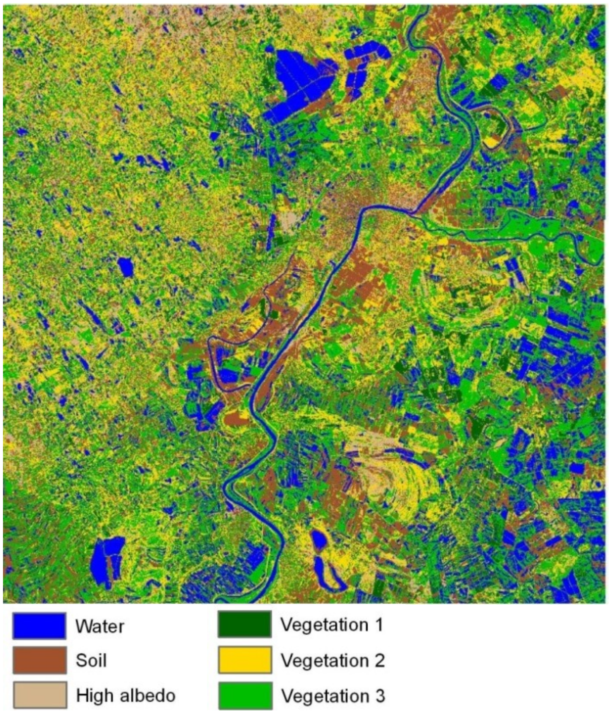

Fig. 4 Maximum likelihood classification result

Spectral mixture analysis

The overall accuracy of the SMA classification was 0.75 (Table 4). The accuracy of the Inland excess water (1) and Shallow water classes (8) are about 0.80 though. The Deep water class (6) is often misclassified as Soil (7). The reflectance of water is influenced by many factors, like suspended solids, water depth, bottom sediments, turbidity and color (Moore, 1980). These may cause classification errors. These errors are already appearing in the fraction images (*Fig. 5*). During this processing step, the high soil fraction in the lakes and the Tisza River is clearly visible.

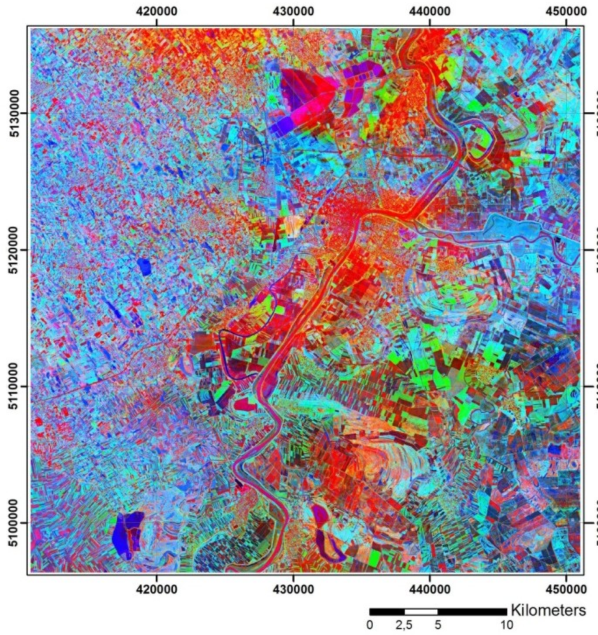

Fig. 5 Color composite of the three fraction maps (Red: soil, Green: vegetation, Blue: water)

The user accuracy of the High albedo class (2) is low due to extreme misclassification of the pixels as Bare soil (7) *(Table 4*). This is happening in areas with sandy soils, which have a very high reflectance.

On the thematic map resulting from the ML classification of the spectral mixture analysis result, it can

Table 4 Cross table showing the training validation of the spectral mixture analysis classification

Training	SMA result								Number of pixels	User Acc.
	1	2	3	4	5	6	7	8		
1	3318	0	0	0	26	729	0	0	4073	0.81
2	0	75	0	0	0	0	3534	0	3609	0.02
3	0	0	4577	0	0	0	0	0	4577	1.00
4	0	0	153	9783	90	0	0	0	10026	0.98
5	5	0	0	74	5386	0	0	0	5465	0.99
6	1816	0	0	0	1	8147	0	0	9964	0.82
7	0	0	0	0	1	0	9689	0	9690	1.00
8	3	0	0	0	0	0	7519	1417	8939	0.16
# of pixels	**5142**	**75**	**4730**	**9857**	**5504**	**8876**	**20742**	**1417**	**56343**	
Prod. Acc.	0.65	1.00	0.97	0.99	0.98	0.92	0.47	1.00	0.65	**OA= 0.75**

be seen that Deep water (6) is sometimes misclassified as Soil (6) (*Fig. 6*). The large lake in the North (Fehér tó) and the Tisza River are assigned to the Soil class. The classification results of the Inland excess water class (1) are similar for all three classification methods. The High albedo class (2) is occuring the least often. This class is only found in smaller patches in the north west of the thematic map.

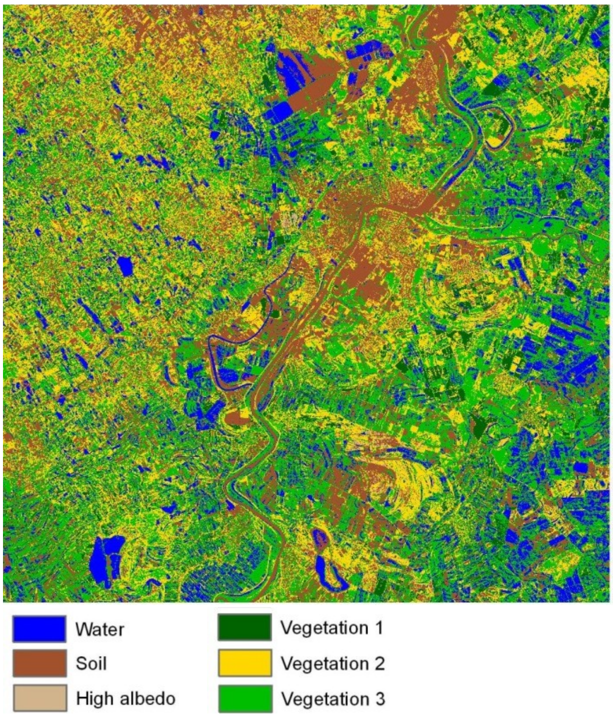

Fig.6 Spectral mapping analysis result

Artificial neural network

The classification using an artificial neural network also mixes the different water classes (1, 6, 8) (*Table 5*). Combining these classes into one bigger class increases the producer accuracy from 0.84 to 0.99 and the user accuracy from 0.68 to 0.99. Other misclassification only rarely happen resulting in an overall classification of 0.96.

The thematic map showing the classification result of the ANN method (*Fig. 7*) is similar to the ML result, although more areas are classified as High albedo (2) and less as Soil (7). Like with the SMA method, a part of the Fehér tó is misclassified as Soil. The Vegetation 3 class (5) is less common in this result compared to the other two methods, while the Vegetation 2 class (4) can be found more frequently.

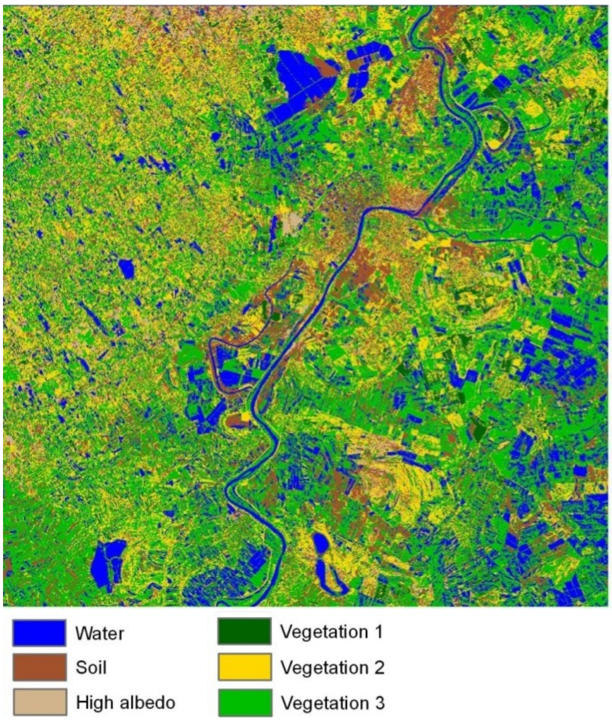

Fig. 7 Artificial neural network classification result

Comparison

All three classification methods result in a map showing areas where inland excess water was occurring during the acquisition of the images. Visually, the results seem quite similar, but the statistical comparison shows large differences (*Tables 4-6*). The SMA classification shows the lowest overall accuracy, but this is mainly due to the misclassification of one class. The ML and ANN meth-

Table 5 Cross table showing the training validation of the artificial neural network classification

Training	**ANN result**								**Number of pixels**	**User Acc**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**		
1	2754	0	0	0	18	1297	0	4	4073	0.68
2	0	3542	0	0	0	0	67	0	3609	0.98
3	0	0	4565	12	0	0	0	0	4577	1.00
4	0	0	10	9965	42	0	9	0	10026	0.99
5	25	0	0	61	5377	1	0	1	5465	0.98
6	508	0	0	0	1	9455	0	0	9964	0.05
7	0	54	0	3	3	0	9630	0	9690	0.99
8	0	0	0	0	0	0	3	8936	8939	1.00
# of pixels	**3287**	**3596**	**4575**	**10041**	**5441**	**10753**	**9709**	**8941**	**56343**	
Prod. Acc.	0.84	0.98	1.00	0.99	0.99	0.88	0.99	1.00		**OA=0.96**

ods have similar overall accuracies. The Maximum Likelihood classification method is relatively simple and requires the least user input.

The overall accuracy is based on the principal diagonal of the confusion matrix only, and thus does not use the information from the whole confusion matrix. The Kappa coefficient (Cohen, 1960) though provides a measure of agreement between predicted values and the observed values while using all information in the confusion matrix (Tso and Mather 2009). Its value is always less than or equal to 1. A value of 1 implies perfect agreement and values less than 1 imply less than perfect agreement. Table 5 shows the Kappa and overall accuracy values for the three classifications.

Table 6 Accuracy measurements of the three classification methods

	Overall accuracy	Cohen's Kappa
Maximum Likelihood	0.95	0.94
Spectral mixture analysis	0.75	0.71
Artificial neural network	0.96	0.96

Also the amount and type of water differs per methods (*Fig. 8*). Most pixels are classified as Inland excess water with the SMA method, while with this method the Shallow water class is identified far less frequently. The inland excess water pixels are probably classified as shallow water by the other methods.

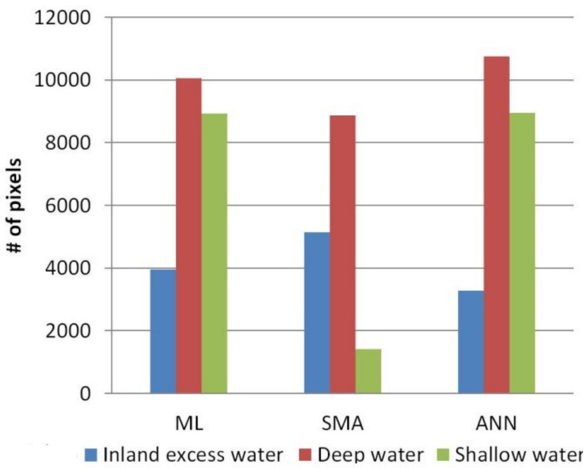

Fig. 8 Distribution of water classes per classification method

CONCLUSION

All three methods can be applied to classify inland excess water successfully and provide high quality maps of the inundations based on satellite data from a large area. There are difficulties for all methods though to distinguish between different type of water classes. The overall accuracy and Kappa coefficient of all classifications is high, but large individual differences exist. The images of the RapidEye satellite constellation have a high temporal coverage, large spatial coverage and acceptable spatial resolution. This makes them very suitable for inland excess water studies.

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STUDIES OF OXFORD STONE AS A CONTRIBUTION TO ENVIRONMENTAL GEOMORPHOLOGY

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Abstract

Much scientific research has been conducted on Oxford stone, of which the historical buildings of central Oxford, UK are comprised. This paper reviews all published literature to-date specifically for Oxford stone, compiling an inventory of studies. The context for this review is in the application of environmental geomorphology to the more recent studies by physical geographers. Overall findings across published studies assist with an understanding of current trends in the conservation of Oxford's historical buildings. Early observations remain generally representative of the findings, although the more recent literature has employed modern methodologies in science and technology that were not available in the late 1940s. Some indication of remaining research gaps are identified and forthcoming research presented. Last is a discussion of current practice in the cleaning and replacement of building stone that briefly considers the authenticity of Oxford stone, which is relevant for heritage conservation. The contribution of such studies to environmental geomorphology is addressed.

Keywords: limestone, historical buildings, soiling, human-environment relations, photogeomorphological approach, conservation, authenticity

INTRODUCTION

The search for contextual similarities between traditional landscape analyses and heritage-orientated research

Much research has been published over the years on Oxford stone that has contributed to a better understanding of the degradation and deterioration of building stone. Geologists and geomorphologists at the University of Oxford have examined the various types of limestone comprising Oxford's historical buildings. The emphasis shifted from a focus on the stone and different types of limestones and their sources from local quarries (in Oxfordshire, but also further afield in Leicestershire and Gloucestershire, etc.) to environmental geomorphological studies of the impacts of air pollution on weathering and the condition of the buildings. Most recently, a photogeomorphological approach was taken up (Thornbush, in press a), where the buildings were depicted as they appeared in photographs from archival and recent records.

This paper reviews the more prominent published studies for Oxford stone. It begins from the earlier work of the geologist W.J. Arkell, who was a Senior Research Fellow of New College in 1933-1940, and continues with more recent works, including by physical geographers, such as by H.A. Viles since 1996, when geomorphologists began to examine Oxford's historical buildings in the context of heritage conservation. These later studies are considered to be exemplar of environmental geomorphology, as a subfield of geomorphology that is within an applied geomorphology (*Fig. 1*). This has two branches connected with environmental geomorphology, and specifically human-environment relations, comprising physical (natural) and human (cultural) components of landscapes.

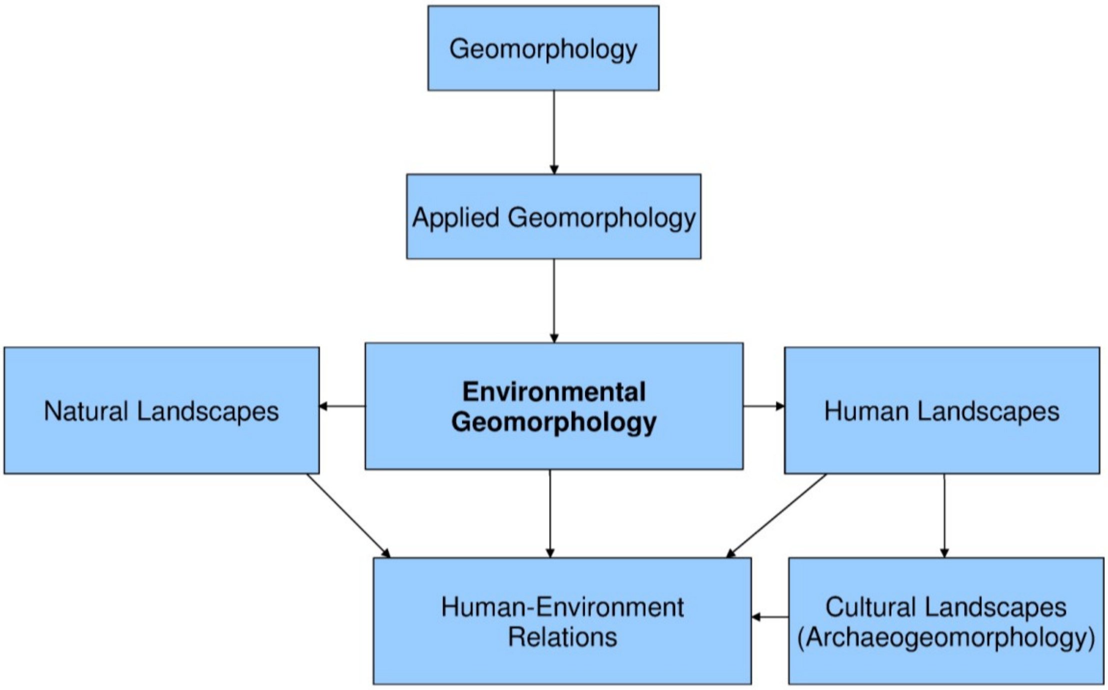
The geologist Coates (1971) introduced environmental geomorphology as part of the then emerging field of environmental geology. According to him, environmental geomorphology '...is very broad and diverse, and includes [humans] and [their] role in terrain activities'. This breadth complicates the task of fully covering the topic. Papers contained within the compilation had been presented at the Environmental Geomorphology Symposium held in the Department of Geology, State University of New York at Binghamton on 16-17 October 1970. He presented the subject content in three parts: 1) watershed planning; 2) regional and local studies; and 3) societal and educational perspectives. This was to commemorate the 'Environmental Decade' (of the 1970s), and the conference was devoted to examining the role of the geomorphologist in environmental studies. He argued that '...during these times of urban renewal and suburban sprawl, the growing population with its accompanying displacements, the rapid expansion of highway networks, and various terrain distortion activities, the geomorphologist has all too often been passive or played only a subsidiary part in any planning or decision-make process'. This stance was developed from the address of interdisciplinary approaches to water resources, as at a drainage basin in southern New York, and the emergence of environmental research in geomorphology. Pending on this and other developments, environmental geomorphology was born out of environmental geology, which itself addresses: '1. Physical data on the terrain itself; 2. Data for management and disposal of wastes; 3. Data for water resources development; and 4. Data on the full range of usable rock and mineral materials and subsurface fluids' Coates (1971). He finally defined the subfield as follows:

> Environmental geomorphology is the practical use of geomorphology for the solution of problems where [humanity] wishes to transform landforms or to use and change surficial processes. Obvious candidates for this study, interpretation, and planning include land-fill operations, ground-water mining and subsidence, streamflow regime upsets, and hillslope modifications. In addition, environmental geomorphology includes extraction of surficial materials, and protection of certain landscapes, such as beaches, which benefit [humanity]. The goal for geomorphic environmental studies is to minimize topographic distortions and to understand the interrelated processes necessary in restoration, or maintenance, of the natural balance.

In this way, Coates established human-environment relations conceptually within his notion of an environmental geomorphology. He followed this up with a subsequent publication (Coates, 1972), wherein he identified various issues and themes concerning environmental geomorphology. These specifically included the following: '1). The study of geomorphic processes and terrain that affect [humanity], including hazard phenomena such as floods and landslides. 2) The analysis of problems where [humanity] plans to disturb or has already degraded the land-water ecosystem. 3) [Humanity's] utilisation of geomorphic agents or products as resources, such as water or sand and gravel. 4) How the science of geomorphology can be used in environmental planning and management'.

There was much response to Coates's (1972) Environmental geomorphology and landscape conservation, especially volumes II (on urban areas) and III (nonurban regions). Dury (1975), for instance, found the second volume to be better than the first (which is mostly unaddressed in book reviews and editorials), even though he found that contribution to be mainly representative of the urban theme in the USA (for example, California) and, hence, fails to address problems on a global scale. There is also a lack of address of karst development for urban areas. Jacobs (1977) was more impressed by the 75 pages written by the editor, comprising Coates's overview, text, and references that were considered to be more helpful than the collection of articles. For the latter volume (III), Gregory (1974) acknowledged an awareness of contemporary problems deriving both directly and indirectly from human activity (as presented more recently in Panizza's (1996) model of the relationships between the geomorphological environment and humans; refer to his Fig. 1). The author also appreciates the temporal span of articles represented in the volume, since 1900 (with volume I covering the literature before 1900). He also remarks on the 10% of content written by the editor that effectively outlines the content of the papers, with introductions provided for the three main sections (organised according to the following topics: terrain degradation; soil conservation; and landscape

Fig. 1 The placement of environmental geomorphology within geomorphology



management). The volume contains some rare papers and brings together relevant studies for the subject matter, such as concerning landscape management. Ofomata (1974) considered this anthology to be the most important as it fills a gap in the literature; however, it did not completely portray nonurban environments through the exclusion of the African (for which papers are mainly written in French and should have been translated and included in this volume) and Latin American continents. Again, the volume is dominated by American studies, with some additional coverage of Australia, China, Israel, Japan, and Russia.

Panizza (1996) recognised the contribution of Verstappen (1983) for definition of environmental geomorphological issues. Like Briggs (1981), Panizza (1996) envisioned environmental geomorphology to encompass human-environment relationships from a geomorphological perspective, with the environment approached from an ecological sense. He subdivided geomorphological components into: '...geomorphological resources [(raw materials relevant to geomorphological processes and landforms)]; and geomorphological hazards [(associated with geomorphological instability)]'. Within this environmental component, humans represent: '...Human activity [(identified as '...hunting, grazing, farming, deforestation, utilisation of natural resources and engineering works')]; and Area vulnerability [(occurs due to human intervention, such as '...population, buildings and structures, infrastructures, economic activity, social organisation and any expansion and development...')]'.

Around this time, Coates (1982) also published in the book Applied geography: Selected perspectives. His paper on Environmental geomorphology perspectives addressed its potential contribution to land-water ecosystems and focussed on food, population, and energy. Subsequent books included Developments and applications of geomorphology, where Fisher (1984) discussed coastal environmental geomorphology in applied coastal research. Environmental and dynamic geomorphology included a paper on environmental geomorphology in Hungary by Pécsi (1985), as a part of applied geomorphological research. Geomorphology and environmental changes in tropical Africa was a special publication that included a paper on the fluvial environment of the Tana River, Kenya by Ojany (1986) that addressed environmental geomorphology. Physical geography and geomorphology in Hungary also contained a paper by Pécsi (1986) that comprised of problems involving the utilisation of the environment.

In addition to these earlier books on environmental geomorphology, papers were also disseminated explicitly as part of international conference proceedings. For instance, the Proceedings of IGARSS '84, Strasbourg, France, where environmental geomorphological studies in the Himalaya, India were based on the analysis of aerial photographs and satellite images and gave consideration to the degeneration of environment (Prasad et al., 1984). Prasad (2008) subsequently published a book on Environmental geomorphology that defined it as '...the scientific study of morphological process and landforms with respect to nature' (preface). He stipulated that the subdiscipline is primarily concerned with surficial physical features of Earth history. However, he acknowledged that these Earth processes and landforms are influenced by human interactions, what he referred to as 'eco-culture' or 'physico-cultural phenomena', which is particularly prevalent in the 'techno-scientific era'. At this time, humanity has destroyed nature due to its constructions and contributed to 'eco-degradation' hazard, ensuing on what he terms an environmental disaster that has challenged scientific research and spurred the need for 'eco-protection', causing geomorphology to meet with environmental science. The author mentioned relevant problems, such as the protection of environmental diversity, establishing ecological balance, and 'eco-development' as part of conservation. Environmental geomorphology's connection with the Earth sciences also brings into question natural resources and land use. Further to this, derived from the first international geomorphological conference held in Manchester, UK, was Environmental and dynamic geomorphology: Case studies in Hungary edited by Pécsi (1985), which portrayed environmental geomorphology in Hungary. Most recently, *Zeitschrift für Geomorphologie* published the proceedings of the second international conference on geomorphology: Geomorphology and geoecology held in Frankfurt am Main, Germany in 1989 and included perspectives of environmental geomorphology by Coates (1990).

There have also been journal articles published as part of environmental geomorphology in various different languages. The *Natural Sciences Journal of Hunan Normal University* published a paper in Chinese by Deng (1986) that placed the role of environmental geomorphology (along with regional and applied geomorphology) as a practical approach to territorial adjustment. The *Boletim de Geografia Teoretica* published a paper by De Barros Goes (1988) in Portuguese that was an application of environmental geomorphology at Rio de Janeiro. Timofeev (1991) examined the object, aims, and tasks of environmental geomorphology in an article published in *Geomorfologiya* in Russian. The author approached environmental geomorphology as a new trend in science at the interface between geomorphic systems and human ecology. *Zeitschrift für Geomorphologie, Supplementband* published an article by Pécsi (1993) on environmental geomorphology in Hungary, which advocated that this new research trend was born of practical topographic assessments (similar to the earlier practical approach to territorial adjustment by Deng, 1986). Importantly, he delineated the subject and goals of environmental geomorphology as different from geomorphology at large because of its focus on the consequences of human intervention, as in the development, change, and state of landforms from a practical perspective. *Sbornik Ceske Geograficke Spolecnosti* published a paper by Ivan (1993) in Czech that considered the cultural landscape and discussed environmental geomorphology as comprising research problems associated with cultural and disturbed landscapes.

There is a lack of theoretical development in environmental geomorphology in more recent years. For this reason perhaps, some studies do not claim to be a part of this subdiscipline even though the work is essentially environmental geomorphological in scope. For instance, Martín Duque et al. (1998) performed a landscape reclamation study representative of environmental geomorphology; however, the authors do not refer to environmental geomorphological explicitly within the article outside of the keywords. They did, however, instigate a methodological application. More recently, *Environmental Geology* approached hazardous wastes from an environmental geomorphological approach, arguing that environmental geomorphology normally lacks detailed environmental impact assessment (Yesilnacar and Cetin, 2008). These authors also presented a predominantly methodological study that is typical of environmental geomorphological research, with its emphasis on the development of methodology over theory. Finally, Mahaney (2012) most recently examined the implications of extreme heating events for an environmental geomorphology in a paper published by *Geomorphology*. This paper similarly focussed on a methodological approach based on rock weathering in a geological investigation that was essentially driven by material testing (methodology, as through the use of scanning electron microscopy or SEM) rather than aimed at a greater theoretical framework. Nevertheless, another paper published recently by Garcia et al. (2012) based a study of the Dam Rio Verde-Parana in Brazil on an environmental geomorphology, with its aims reflecting concepts within the subfield, including the identification of both its environmental compartments as well as regional geology and physiography and human impacts in the area. These authors discovered an intense human influence, such as of urban growth, natural hazards (including mass movements and flooding), and a fragility of the landscape created by agricultural land use.

Perhaps the most unifying principle of environmental geomorphology is its emphasis on the practical use of geomorphology in order to solve problems associated with surficial processes and materials that may appear as landforms. As part of an applied geomorphology, environmental geomorphology could also abide by the principles and practice of an applied geography, as outlined by Briggs (1981) as part of a problem-orientated discipline. Specific problems identified by the author include: '...pollution, damage to wildlife, destruction of habitats, soil erosion and resource depletion; the problems of human deprivation and inequality'. In this way, he conveyed problems associated with both natural (physical) and cultural (human) landscapes (see *Fig. 1*). Moreover, his article has a more developed section on the method of applied geography than when addressing the subject matter of applied geography, which is similar to other published studies relevant to the subdiscipline. Panizza (1996), for instance, differentiated a model of the geomorphological environment and humans (with active and passive branches), affecting impact and risk (refer to his Fig. 1).

This practical subdisciplinary approach often targets human-environment relations and is apparent in several recent studies in the literature. For example, a geoarchaeological study of Australia considered past human-environment interactions, focussing on influences of human behaviour as distinguished from environmental impacts on key topics (Holdaway and Fanning, 2010). 'Human-made landforms' are referred to in terms of human-environmental interactions in mountain regions, including the Sudetes Mountains, Poland (Latocha, 2009). These (human-made landforms), comprising more persistent types in the landscape, for example agricultural terraces, as well as disappearing anthropogenic features, such as field roads, are differentiated from natural landforms (Latocha, 2007). Other authors have developed a history of human-environment interactions (in the Late Holocene), noting some important (anthropogenic) events, such as the onset of agriculture in the Yame' River valley on the Bandiagara Plateau of Dogon country, Ounjougou Mali, and the increasing role of human-set fires and food production (Ozainne et al., 2009). Since hydrology affects the livelihoods of rural communities and is an integral variable affecting desertification (Huber-Sannwald et al., 2006), rivers have received much attention within an environmental geomorphology; as for example, tracking the evolution of the Yellow River in China in consideration of the physical components of the landscape (geological structure, climate) in addition to the human environment (Li et al., 2003). Such human-environment interactions have been regarded as relevant for study by natural scientists and are used to diagnose social and cultural change (Rapp and Jing, 2011). Human land use has been central to approaches advocating human-environment interactions in conjunction with process geomorphology (e.g. Enters et al., 2008), many stipulating sustainable land use (e.g. assessments of natural versus ecoenvironmental vulnerability, as in the Apodi estuarine in northeast Brazil; Boori and Amaro, 2010, 2011).

The purpose of this study is to present (known) published works for Oxford stone in order to develop a discussion of this research that has implications for conservation policy and practice. The overarching aim is to delineate the different works in order to arrive at a current understanding of this record of historical buildings in the context of environmental geomorphological studies. Specific objectives are to review scientific research by various authors who have made a contribution over the years to studies of Oxford stone, and discuss the future of Oxford's historical buildings. This paper outlines the state of the art and critically discusses directions taken in science and technology and its implications for stone conservation policy and practice. Ultimately, this is a contribution to the literature in environmental geomorphology by placing studies of Oxford stone as part of an applied geomorphology within the specific jurisdiction of environmental geomorphology (as denoted in *Fig. 1*), as part of cultural landscapes within a more human facet of the subdiscipline that engages with the conservation of cultural landforms and landscapes.

Oxford stone

The published book by Arkell (1947) Oxford stone made the first significant contribution to an understanding of the variety of limestones comprising Oxford's historical buildings. His geological perspective is captured in this book, with much emphasis on the different types of limestones and where they were quarried, except for the final chapter on The decay, repair and maintenance of Oxford buildings, where he focussed more on the condition of buildings during his time. In his Chapter 8, Arkell (1947) made several observations about Oxford stone, which he accounted was transformed due to much refacing in Bath and Clipsham stones. For instance, Bath stone needed replacement every 200 years, with large-scale renewal occurring in 1850-1860 at various colleges, including Queen's, Exeter, Jesus, All Souls, and Balliol Colleges. The majority of restorations occurred in 1900-1912 with the introduction of Clipsham stone, a durable variety of stone. Buildings were observed to be thickly covered with ivy and creeper, such as Magdalen (cloisters), Exeter (quadrangle), and Balliol (west front) Colleges until some 20 years before the publication of his book, with Christ Church (meadow buildings) being loaded with greenery still in his time. Then, some buildings still retained some of their original stone, where stone decay could be studied at the Sheldonian Theatre, Radcliffe Camera, Bodleian (lower stages), Christ Church (library, Canterbury quad and gate), Trinity (chapel), Pembroke (chapel), Worcester, Corpus Christi (fellows building), and the old observatory. Elsewhere, Arkell (1947) noted that buildings had been modified through patching, scraping and even the use of preservatives. In his chapter, Arkell (1947) considered the various weathering processes and features evident then, including encrustation, blistering and exfoliation; warts; cavernous decay; weathering along bedding planes and granular disintegration; solution of the fine matrix as well as chemical decay along contacts (of limestone with sandstone); fracturing due to the use of iron cramps and dowels; vibration from road traffic on High Street; creepers as well as lichens and algae; and last is his address of the future of Oxford stone.

His observations on the weathering of buildings were to become the basis of geomorphological research. He observed that crusts commonly developed on Oxford stone, and that this was the most serious type of weathering, particularly for Headington freestone that appeared in Oxford in 1885. The formation of these skins developed through the accumulation of gypsum (calcium sulphate) from smoke released in the burning of coal. Arkell (1947) described it as follows: 'The surface of this [Headington free-] stone on exposure to the weather forms a hard, impermeable, black crust and the skin curls up and peels off. In time a new skin begins to form and the process is repeated'. Viles (1993a) delineated a three-stage conceptual model of blistering, which concurs with his observations. Moreover, a study on the environmental pollution of Oxford confirmed that restorations were frequent when colleges were burning sulphurous coal transported by way of the Oxford canal (Viles, 1996a). The outline by Arkell (1947) of skin formation is as follows:

> The blistering of the skin, with formation of an empty cavity behind it, seems to be due to the fact that the calcium sulphate skin has different physical properties from the stone (calcium carbonate) behind it and so reacts independently to changes of temperature and moisture, until eventually it parts company. In particular the skin expands more than the stone when heated by the [S]un, and the blistering is a natural response to the conflict of forces so set up.

Studies of temperature in the formation and exfoliation of skins have been mostly neglected for Oxford apart from a study by Viles, (1993b), who examined the impact of orientation on weathering features like blistering (on south-facing walls). Moisture through walls (but not Oxford fogs or drizzle in the making of sulphuric acid) was examined by Sass and Viles (2010a), who found more moisture in locations of decay, such as under blackened crusts. Experiments using simulated driving rain showed that weathered blocks absorb more water and this occurs at a faster rate than by crusted or replacement blocks (Sass and Viles, 2010b). However, they reported that these decayed blocks also dried up faster than other blocks. Temperature may be an important variable that has not received as much attention as it perhaps should, especially since Arkell (1947) noted that blistering was worse on south walls that receive more daytime sunlight (and experience the most temperature changes); as for example, any Headington freestone still remaining in the Bodleian quadrangle. Where moisture is not the culprit, irregularities in stone hardness (as well as any nodular structure) could lead to cavernous decay, which could develop to a depth of several inches. Goudie and Viles (1997) published a book on Salt weathering hazards that addressed the occurrence of salt weathering, which has been known to include cavernous weathering. More work, however, could be done field-testing for stone hardness in order to account for the ribs or 'bars' that Arkell (1947) outlined as part of the 'toning down' process in addition to cavernous weathering. He also mentioned the mechanical etching of wind-driven rain and hail, which was examined in a study of soiling and rainwashing due to wind-driven rain from the southwest along the south side of the Ashmolean Museum by Thornbush (2010a). This was not, however, directly on etching or at Jesus College, where damage was attributed by Arkell (1947) to acidity enhanced by organic matter from the covered market. He addressed rising capillary from the water table, which affected the base of columns, as on the south side of the Clarendon Buildings. He did refer to capillary action into sandstone, which has a greater porosity than limestone, leading to the enhanced decay of sandstone along limestone-sandstone contacts, as evident on the plinth of the Ashmolean Museum. Porosity may also increase as stones decay. It would have been helpful to address the role that condensate (settling close to ground-level in a cold, humid location) will have on the weathering of limestone.

Studies have not followed up on some areas addressed in the book by Arkell (1947). Some have already been outlined, but others remain to be mentioned. For example, research has not addressed the excessive use of iron cramps and dowels to emplace Bath stone, which led to fracturing and spalling of the stone. Even though much research has addressed the impacts of traffic pollution due to the Oxford Transport Strategy and its monitoring (e.g. Viles, 1996b), the impact of traffic on vibrations, especially along busy streets like the High Street, has not been investigated. Arkell (1947) presented a study conducted in 1932 at University College to monitor vibrations on the High Street using a Milne-Shaw seismograph. It would be interesting to revisit this research and follow-up in order to test for any weathering features more predominant where there are more vibrations from traffic, such as cracks due to structural instability and damage.

In his final book chapter, Arkell (1947) addressed several biota, including creepers, lichens and algae. In his time, it appears that there was some hostility towards ivy and creepers, and their use was highly controversial. There is no doubt that this controversy continues today, when organisations like English Heritage are struggling with whether ivy should be carefully managed and have invested in research into their bioprotective versus biodeteriorative impacts. Arkell (1947) took the stance that creepers should be kept away from already weathered buildings, such as those experiencing crumbling and/or exfoliation. His concern was that the mechanical action of creepers, ivy in particular, will hasten the weathering process. For example, even the wind can pull them and move them about, potentially contributing to damage when these climbing plants pull material. However, he was of the opinion that sound buildings could withstand the use of ivy and creepers, assuming that the plants' growth is controlled (e.g. away from windows and eaves and not allowed onto roofs). He identified some advantages to such climbers, which included their ability to hold moisture to the wall and keep it damp (this could, however, evoke chemical weathering). This was also recently supported by Sternberg et al. (2011), who found higher relative humidity on ivy-covered walls relative to uncovered (exposed) walls. Arkell (1947) also observed that the leaves of these plants act like tiles, shedding off water, which offers walls some protection from rainwashing. The only similar line of research to test this latter observation was also by Sternberg et al. (2010), who advocated that ivy also protects walls from the deposition of dust particulate due to shielding by leaves. However, they did not address deleterious impacts that Arkell (1947) mentioned, for instance that the tendrils and suckers can secrete acids enhancing decay. He described that these tendrils and suckers become attached to walls and coat them with a hard woody substance, which is visible when the plant is removed. This was observed by Arkell (1947) at Exeter and Lincoln Colleges, where he attributed it to the clearance of ampelopis. He did seem to favour the greenery produced by such plants, suggesting that they improved the aesthetics of buildings, particularly those without perfect symmetry and masonry. He valued the use of controlled creepers like at Lincoln and Pembroke Colleges, and found that the plants made these places more pleasant, especially in the summer. For example, amepolopsis growing at New College is green in the summer, but turns crimson in the autumn. His concluding view, however, was that research should focus on testing for the harmfulness of ivy and creepers, for instance as was evident at Lincoln College, in places previously occupied by creeper that were subsequently decayed, with creeper as a possible cause. In this latter case, Arkell (1947) suggested keeping the wall clear of creeper. Nevertheless, he did believe that flowering plants, like wistaria, should be allowed to grow on plain walls, even if harmful. His view of lichens and algae, on the other hand, was that they offered a protective covering and showed no sign of harm to the stone. This latter point is also a point of contention in the literature on biodeterioration.

Other studies

Many publications have followed the classic volume by Arkell (1947), most of it linked to work by Viles driven by some funded research projects. The first of these projects concerned the environmental monitoring of the Oxford Transport Strategy of June 1999 (Viles, 1996b). Here, the concern was over the impact of air pollution on Oxford stone due to traffic. This project involved three strands of research, including exposure trials and photographic monitoring of walls. Sensors exposed at roadside locations were examined by Viles and Gorbushina (2003) after up to three years of exposure. They found that sensors located on busier roads became soiled faster; that all sites experienced bacterial, fungal (especially within surface hollows) and phototropic colonisation (particularly at a background site that had higher colonisation of organisms after just three years), included particulate matter deposits, and also conveyed calcite dissolution. These findings led to a detailed study of fungi on these oolitic stone sensor samples (Thornbush and Viles, 2006a). For the second strand of the project, photographic surveys were extended from 1997 to 2003 to encompass six years of monitoring (Thornbush and Viles, 2008). This photographic survey involved an integrated qualitative-quantitative approach; however, other studies quantitatively assessed soiling and decay of the building stone (e.g., Thornbush, 2008a).

Participation in a newly funded project on catastrophic decay in building limestones led to more published work on Oxford's oolitic limestones. When Smith and Viles (2006) compared limestone with sandstone building stone, they discovered a patchiness and contagiousness in the former that was connected to catastrophic decay. Gomez-Heras et al. (2010) more recently published a paper on 'Oxford stone revisited' in the fashion of Arkell (1947) that examined the diversity of building limestone in the historical buildings. Most recently, English Heritage funded a project Ivy on Walls that generated some research into the bioprotective versus biodeteriorative effect of keeping ivy, in particular, on walls. Two studies by Sternberg et al. (2010, 2011) were already mentioned, but some work was also performed by Thornbush (2008b, 2012a) based on photoarchival searches in college archives, including at Trinity and Pembroke Colleges.

Some studies have presented new methods or approaches for use on Oxford stone. Soiling was examined at various scales from stone sensors exposed during the environmental monitoring of the Oxford Transport Strategy using the integrated digital photography and image processing (IDIP) method by Thornbush and Viles, (2004a, b) to entire blocks on the boundary wall of Worcester College with the decay mapping in Adobe Photoshop (DMAP) approach developed by Thornbush and Viles (2007a). A novel technical approach was taken with the application of portable X-ray fluorescence to the same wall (2006b), finding high levels of iron on newly replaced stone blocks that possibly conveyed weathering through iron migration to the stone surface (rather than iron deposits). An earlier study by Inkpen et al. (2001) used geographic information systems (GIS) to map decay derived from a time sequence based on old photographs taken of Oxford stone. Later, Inkpen et al. (2008) presented an integrated database and GIS that was used to record and monitor Oxford stone degradation. Sun et al. (2010) designed a new optical fibre humidity sensor for monitoring building stone deterioration.

DISCUSSION AND CONCLUSION

Much has been learned about the soiling and decay of Oxford stone. Even though Arkell (1947) did not systematically test his observations, making only qualitative judgements of stone weathering in his final chapter, what he did observe has been generally supported by scientific research. However, not all of his observations have been tested, for instance algal cover is still not yet addressed in the published literature for Oxford, except for a quantitative study by Thornbush (in press b). Lichens have been examined through rooftop experiments in Oxford by Carter (2002) and Carter and Viles (2003). More research needs to be conducted with aspect (wall orientation) in mind, which will affect microclimate (temperature in particular) and the development of lichens and algae. (Thornbush is currently working on a lichen study that quantifies lichen distribution across a string course in the Oxford city centre, where she considers microclimatic effects, including aspect).

Further microclimatic studies are still needed to examine the weathering features found on historical buildings in central Oxford. The use of a climatic chamber (as by Thornbush and Viles (2007b), who tested for the dissolution of weathered versus unweathered surfaces in differently concentrated solutions of carbonic acid) would be ideal for this kind of work in order to support any field experiments. Temperature, as well as moisture, variations should be considered in these studies. Needless to say, more research is needed to address any potential harmful effects of ivy on walls, including physicochemical analyses that test for chemical secretions and their acidity. This is relevant because decaying plant matter also generates acids that could be harmful to Oxford stone even in nonacidic (clean) air. This is considered in detail by Thornbush (in press c) in a recent publication that addresses the biodegradation and biodeterioration of limestone surfaces covered with vegetation (climbing plants in particular). More attention to the archival record for past use may be beneficial to understanding the use of climbing plants at Oxford colleges, including case studies at Christ Church, Exeter, and Lincoln Colleges. It is also relevant to investigate the different impacts of evergreen (ivy) versus deciduous (creeper) varieties. This would provide a cross-temporal context similar to the study by Thornbush (2010b), which reexamined a selection of buildings included in restoration photographs taken by the Oxford Historic Buildings Fund between 1957 and 1974. More recently, Thornbush (2012b) has devised a simple photo-based weathering index, namely the S-E index, for classifying soiling and decay damage to historical limestone based on a laneway in central Oxford, where a majority of buildings have not been cleaned or refaced in recent years. This classification system takes into account physical, chemical, and biological weathering processes and is based on the quantification of visible weathering forms. It has been applied most recently at churchyards located centrally in Oxford by Thornbush and Thornbush (in press a).

The conceptual framework for this paper is based on environmental studies performed in urban environments. They have encompassed studies employing a variety of both quantitative and qualitative methods, as outlined in *Table 1*. Moreover, these studies within an environmental geomorphology address both human and natural (physical) landscapes as well as human-environment relations. Topics have included land use (urbanisation, conservation); pollution (from energy production, such as from coal fires and transport); and microclimate (temperature, moisture). These main themes have, respectively, produced works addressing vegetation cover; acid rain; and aspect.

Perhaps one of the greatest contributions of the current research is its use of photography. Such a photogeomorphological approach taken initially by Viles (e.g. 1994) in her photographic monitoring and taken up and developed by M.J. Thornbush since 2004, is an advantage because of its contribution to an expanding photographic record, which could be used cross-temporally by various workers to develop new methods to examine the degradation and deterioration of Oxford stone. Some Oxford colleges also house extensive archives that could help extend the temporal photogeomorphological record back to the middle of the 19th century. These enable longer term studies that examine the visual appearance of Oxford stone, including any weathering features (especially if visible close-up). For example, as in the cross-temporal study of traffic congestion and stone decay that was conducted using archival material (including photoarchival) at Magdalen College (Thornbush and Viles, 2005).

Table 1 Methods used in Oxford studies

Method	Chronology of references
Vibrations (seismograph)	Bowen in Arkell (1947)
Field surveys	Viles (1993b); Smith and Viles (2006); Thornbush (in press c); Thornbush and Viles (2008)
Exposure trials	Viles (1996b); Carter (2002); Carter and Viles (2003)
Mapping and GIS	Inkpen et al. (2001, 2008)
Scanning electron microscopy (SEM)	Thornbush and Viles (2006a); Viles and Gorbushina (2003)
Portable X-ray fluorescence (PXRF)	Thornbush and Viles (2006b)
Simulation experiments	Thornbush and Viles (2007b)
Computer processing	Thornbush (2008a, 2010a, in press b); Thornbush and Viles (2004a, 2004b, 2007a)
Archival studies	Thornbush (2008b, 2012a); Thornbush and Viles (2005); Viles (1996a)
Petrographic analysis	Gomez-Heras et al. (2010)
2-D resistivity surveys	Sass and Viles (2010a, 2010b)
iButtons	Sternberg et al. (2010; 2011)
Optical fibre humidity sensors	Sun et al. (2010)
(Re)Photographic surveys	Thornbush (2010b, 2012b, a); Thornbush and Thornbush (in press a, in press b); Viles (1993a, 1994)

Thornbush and Thornbush (in press b) are currently working on a book entitled Photographs across time that portrays physical and cultural landscape change in urban settings, including Oxford, in a rephotographic approach.

Another major contribution of these studies is as exemplar of environmental geomorphology within an applied geomorphology in the realm of heritage science conservation. Since this geomorphology subfield has already been delineated in earlier works (such as Panizza (1996) in an introduction to environmental geomorphology), the current review encapsulates Oxford stone as part of this applied geomorphology, providing a further case study to supplement the published Hungarian case studies. The current case study also aligns well with the multidisciplinary approach comprising geomorphic systems and human ecology outlined by Timofeev (1991), as well as the emphasis on cultural landscape advocated by Ivan (1993). It also supports recent frameworks developed by the author (Thornbush, 2012c), who recently outlined the inclusion of archaeogeomorphology as a subfield of an applied geomorphology that examines cultural landscapes. Environmental geomorphology would encompass archaeogeomorpholgoy, and cultural landscapes with a human-oriented geomorphology (in addition to more traditional (physical) landscape geomorphology), and would in turn be an applied (practical) geomorphology (see *Fig. 1*). More specifically, as denoted by several other authors (Fisher, 1984; Pécsi, 1985, 1993) environmental geomorphology is a practical (applied) geomorphology. As such, for Oxford, it provides a framework for studies in the degeneration of the (built) environment (Prasad et al., 1984). It also encapsulates practical problems of utilising the environment in these urban settings conveyed by Pécsi (1986) and the consideration given by Coates (1990), conveying environmental geomorphologists as scientists who are concerned with solving societal problems, including where natural surface processes have affected the built environment (installations and properties) as well as where they are changed by human activity, such as the the deterioration of Oxford stone through (among other reasons) exposure in a polluted environment due to combustion.

This paper does not consider either the variety of limestones used in Oxford's historical buildings, nor does it consider methods of repair and maintenance in any detail. However, it does pick up on the discussion by Arkell (1947) of the future. At the end of his Chapter 8, he conveyed that in the past Oxford colleges employed their own masons, but that the trend now is to contract out the work. In his time, only Magdalen, Wadham, and Exeter Colleges still employed their own mason. Today, however, some colleges do keep clerks-for-works or architects. The problem of keeping the latter, however, is that architects are not necessarily stone conservation experts. Arkell (1947) recognised Oxford's historical buildings as a national heritage, which should be upheld by an advisory panel:

> For that same Fellow will readily agree that Oxford is a national heritage. And if the university as a whole is a national heritage so are the individual buildings that compose it. The university, acting through its advisory panel of architects, university officers, scientific experts, and chosen representatives of the colleges, would seem none too large an authority to take responsibility for the components of such a heritage.

The office of the panel would have many responsibilities, including reporting to the Government Building Research Station. He suggested that the panel obtain its own portable cleaning outfit that would be made available for regular cleaning and treatment of buildings that could promote regular inspections of decay and keep an up-to-date dossier of each building. However, to the author's knowledge, an advisory panel is still missing from the university's administration, which could, as Arkell (1947) suggested, help to bring together different experts and supports within the university, including individual colleges and schools (including laboratories).

The current practice of conserving Oxford stone requires the replacement of blocks that have suffered from cavernous weathering (blowouts) once crusts have been breached and the more friable material beneath collapses. This was evident relatively recently after cleaning at various locations, such as at the boundary wall surrounding Magdalen College along Longwall Street in central Oxford. Cleaning of the stonework does reveal decay features, such as is still evident on the plinth of the Ashmolean Museum even after it was restored recently. Although cleaning brightens the stonework, it does not conceal stone decay damage, which can only be patched-up or replaced. For example, replacement blocks are still evident at the boundary wall of Worcester College, although they are now darkening and less conspicuous. Outside Exeter College facing onto Turl Street, blocks have been (noticeably) replaced on the façade. The Sheldonian Emperors' Heads are another example of replaced Oxford stone that brings into question the authenticity of the fabric of Oxford's historical buildings. Cleaning and restoration works are performed piecemeal by storey, as is evident recently at the Bodleian Library, whose upper storey was restored recently and the middle level cleaned. This practice (of piecemeal cleaning and replacement) makes it difficult to perform temporal studies of stone decay for Oxford's historical buildings. It is also difficult to control the lithology of the type of limestone used even across one façade, as for example at the Ashmolean Museum, which comprises different varieties of limestone in addition to sandstone. Oxford's buildings are often hidden behind scaffolding, which has become an expected part of this urbanscape. Its historical buildings are now a mere cast of what they once were because of various 'face-lifts' over the years, including since the time of Arkell (1947). Even though stone decay has been studied and tested, science cannot solve the problem of Oxford stone's plight with time.

This takes one back to the beginnings of environmental geomorphology and specifically the original work by Coates (1971), with its portrayal of this geomorphology subfield as being conjunctant to landscape conservation. Moreover, the work by Prasad et al. (1984) addressed the degeneration of environment, which suits this examination of studies of Oxford stone. The historical buildings of central Oxford are part of a cultural landscape that needs to be conserved and as a cultural heritage resource that needs to be sustained. By examining how cultural stoneworks change due to exposure in certain environments, such as in polluted urban settings, it is possible to work towards their conservation rather than piecemeal replacement and replication. These studies make a contribution to environmental geomorphology as cultural heritage that is susceptible to (passive) human activities that enhance an area's vulnerability (Panizza, 1996), leading to risks associated with the conservation of this cultural landscape and affecting the sustainability of this resource. By examining human-environment relations within environmental geomorphology, it is possible to better connect the human (cultural) and physical (natural) branches of the environment. This includes considerations of human landforms, as in a built-up urban setting in the current study, rather than just traditional notions of physical landforms previously addressed by geomorphologists.

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MODELING THE IMPACTS OF CLIMATE CHANGE ON PHYTOGEOGRAPHICAL UNITS. A CASE STUDY OF THE MOESZ LINE

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Abstract
Regional climate models (RCMs) provide reliable climatic predictions for the next 90 years with high horizontal and temporal resolution. In the 21st century northward latitudinal and upward altitudinal shift of the distribution of plant species and phytogeographical units is expected. It is discussed how the modeling of phytogeographical unit can be reduced to modeling plant distributions. Predicted shift of the Moesz line is studied as case study (with three different modeling approaches) using 36 parameters of REMO regional climate dataset, ArcGIS geographic information software, and periods of 1961-1990 (reference period), 2011-2040, and 2041-2070. The disadvantages of this relatively simple climate envelope modeling (CEM) approach are then discussed and several ways of model improvement are suggested. Some statistical and artificial intelligence (AI) methods (logistic regression, cluster analysis and other clustering methods, decision tree, evolutionary algorithm, artificial neural network) are able to provide development of the model. Among them artificial neural networks (ANN) seems to be the most suitable algorithm for this purpose, which provides a black box method for distribution modeling.

Keywords: climate change, REMO, Climate envelope model, phytogeography, Moesz line, model improvement

INTRODUCTION

The latest regional climate models (RCMs) have high horizontal resolution and good reliability. They provide projections for the Carpathian Basin that are related to botany (Czúcz, 2010), landscape architecture (Bede-Fazekas, 2012a), and forestry (Mátyás et al., 2010; Führer et al., 2010; Czúcz et al., 2011). Our future climate, which is likely to be warmer, dryer in summer, and have more extreme precipitations in the colder half-year term (Bartholy et al., 2007; Bartholy and Pongrácz, 2008), will enforce changes in the composition of the natural and the planted vegetation. The landscape architecture can have a significant role on the mitigation. We should note, however, the importance of adaptation, since climate change cannot be compensated by the intensive garden maintenance (Bede-Fazekas, 2011). One of the most important tools from the adaptation toolkit of landscapes architecture is the reconsideration of the ornamental plant assortment. There are some papers dealing with this issue (Schmidt, 2006; Szabó and Bede-Fazekas, 2012).

Geographical visualization can be produced with GIS (Geographic Information System) software based on the large amount of tabulated data of the different climate models, which might be interpretable not only by experts. They are able to visualize the direction and the volume of climate change also for non-professionals (Czinkócky and Bede-Fazekas, 2012). This is true in case of different modeling themes, such as the distribution area of the Mediterranean plant species; the distribution area of the plant species migrating northwards from the Carpathian Basin; and the phytogeographical units and borders that may shift from or shift to the Carpathian Basin. Phytogeography, a branch of biogeography, is concerned with the distribution area of plant species, communities and floras. This paper summarizes the experiences gained by the model run on the Moesz line as a case study and highlights the possible improvements of the model, including the application of Artificial Intelligence (AI) algorithms.

There are really few models that have studied the assortment of plants able to spread through or be introduced in the Carpathian Basin in the 21st century. There are, however, numerous researches that have connection with these modeling approaches. The research of Horváth (2008a) about finding the territories having similar climate nowadays to the future climate of Hungary has high importance. He has found that these spatially analogue territories are, for the next 60 years, the following: South Rumania, North Bulgaria, Serbia, and North Greece (Horváth, 2008b). By studying the vegetation and ornamental plant assortment of the analogue territories we can estimate the future vegetation and the possibilities of ornamental plant usage in the future in Hungary.

Among forestry species the distribution of beech (*Fagus sylvatica* L.) has been modeled (Führer, 2008). The impacts of climate change on the natural vegetation and habitats were studied by Kovács-Láng et al. (2008) and Czúcz (2010). Artificial neural network, is one of the artificial intelligence methods described further as a recommended improvement of the model, was used for modeling the inland excess water by Van Leeuwen and Tobak (2008).

Apart from Hungary, there can several researches be found using similar methods to that ones I suggest in the Discussion. One of the most significant is the work of Arundel (2005), which is about finding the climate envelope of five warm-demanding species of North America by significance analysis. Modeling was, however, not carried out by him. Berry et al. (2002) modeled the distribution of 54 species and the composition of 15 habitats of Ireland and Great Britain. Harrison et al. (2010) studied the potential composition change of the vegetation of Oregon. The distribution of 134 North American tree species was modeled by Iverson et al. (2008) with the use of regression trees. Stankowski and Parker (2010) found that regardless of distributional and environmental data, there is not any algorithm which could maximize model performance for all species; thus different species demand different models. Guisan and Zimmermann (2000) give full review of the methods that can be used for ecological modeling.

METHODS OF MODELING

The approach of modeling the shift of phytogeographical units can be reduced to modeling the potential distribution area of fictive or real species bound to the phytogeographical unit. The inputs of the model are the current distribution of the plant species, the climate date for the reference period, and the climate data for the future period(s). There are three main steps: 1) querying the climate demands/tolerance of the species; 2) validating the model (modeling the reference period); 3) predicting (modeling for the future period). The climate requirements of the species can be filtered based on the distribution and the climate data of the reference period, since the extremes of a certain climate parameter indicate the tolerance boundaries of the species. The selection of climate parameters, however, is subjective. Note that the model can fail if not enough or too much

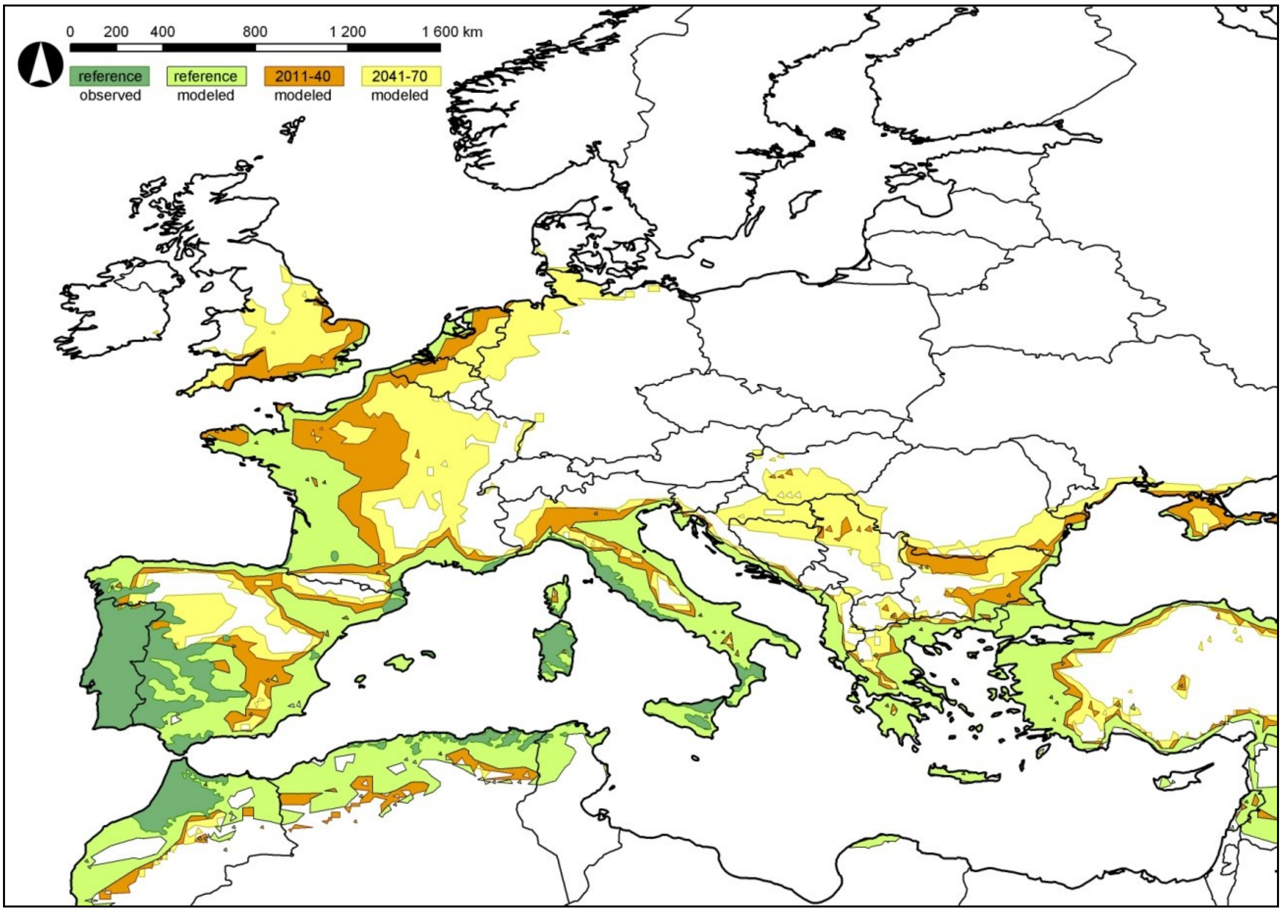

Fig. 1 Observed distribution, modeled potential distribution for the reference period, and predicted potential distribution for the future periods of cork oak (*Quercus suber*)

climate parameters are selected (Bede-Fazekas, 2012a). The result of this phase is a list of climatic limits (a zero-order logical formula in mathematical terms) per species, therefore the climate requirements of the species are written as equations. This is the mathematical basis of the prediction that used in the next phase.

Based on the knowledge of the climate requirements, the territories providing suitable climatic environment for the plant can be filtered according to the climate data of the reference period. The sum of these territories is the potential distribution area. Modeling the potential distribution for the reference period is seemingly unnecessary and negligible, and it does not influence the result. This medial phase of modeling is, however, not to be omitted, since the result of this phase provides for the possibility of validating. The reliability of the future predictions (model results) can be concluded by comparing the observed distribution to the modeled potential distribution. In case of much greater area of distribution the model results are not to be reckoned as reliable results, irrespective from the known influence of anthropogenic, edaphic and competitive effects on the real distribution. Therefore, the similarity of the observed and modeled distribution can guarantee that the model is reliable enough.

Based on the climate demands of a certain plant species and the climate data, the suitable territories can be filtered not just for the reference period but also for the future periods. This third phase is the modeling/prediction approach in the strictest sense; this is about finding the future potential distribution (*Fig. 1*).

The method of modeling the future shift of Moesz line (also called as grape line) is going to be reviewed, which is appropriate example of modeling a phytogeographical unit based on modeling the distribution of separate species. Moesz (1911) observed that the northern borders of 12 plant species are highly correlated with each other, and this line is also the northern border of the vine cultivation area. This phytogeographical line, which is situated near the southern foot of the Western Carpathians, was later named after Moesz. There is hardly any international literature about the Moesz line, since it is of local importance. Note, that elongation of the grape line to the west and to the east results in an extended phytogeographical line which still correlate with the northern border of some species originally bound to the Moesz line (eg. *Muscari botryoides* – Somlyay, 2003). The extended line characterizes not only the flora and ornamental plant assortment of the Carpathian Basin, therefore modeling the Moesz line can have importance for entire continent.

There are several approaches of modeling a phytogeographical line. Three different methods (called line modeling, distribution modeling, and isotherm modeling) are going to be discussed. The models were run by the Spatial Analyst module of the GIS software ESRI ArcGIS. All of them were based on the regional climate model REMO, which has a grid resolution of 25 km. Although the entire European Continent is within the domain of REMO, we used only a part (25724 of the 32300 points; *Fig. 2*) of the grid. The reference period was 1961-1990, while the future predictions were applied for the periods 2011–2040 and 2041–2070 based on the IPCC SPES scenario called A1B.

Isotherm modeling among the three methods is the easiest to apply. It is based on finding that winter minimum temperature isotherm that correlates with the phytogeographical line most of all. The predicted shift of the isotherm probably indicates the shift of the

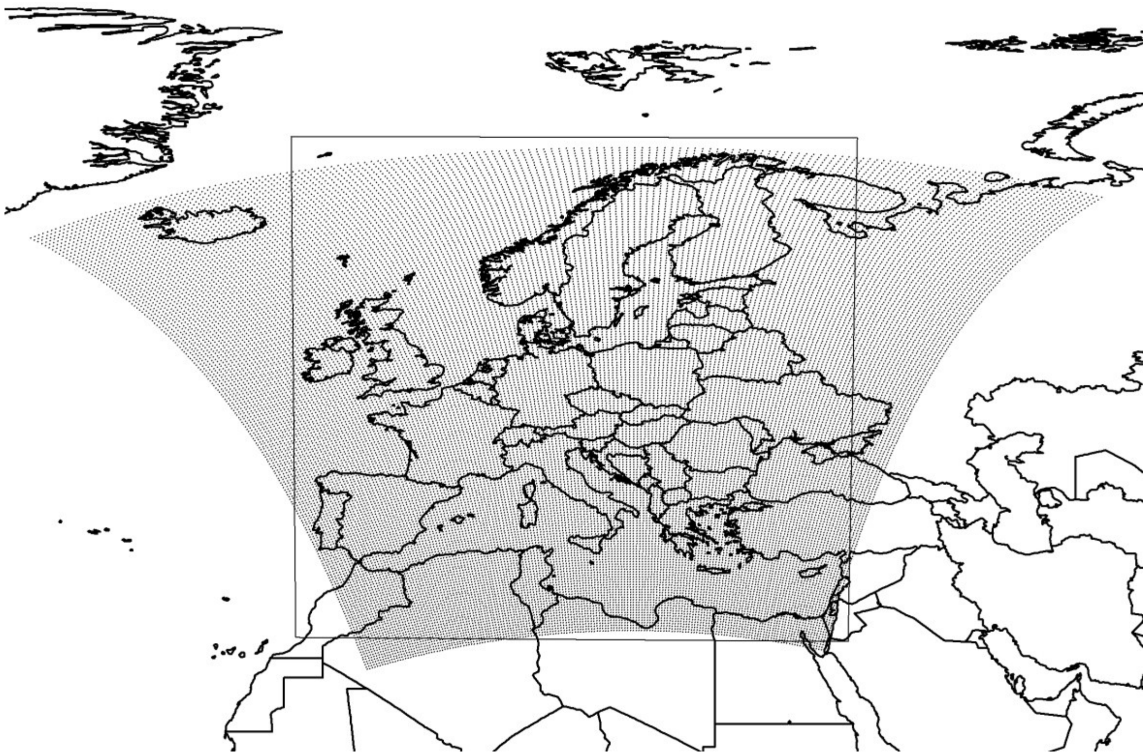

Fig. 2 The domain of regional climate model REMO (grid) and its part used in the study (within the rectangle)

phytogeographical line. The main disadvantage of this method is that the existence of this isotherm cannot be guaranteed in case of all phytogeographical borders (in case of the Moesz line the appropriate isotherm was found). Only one or a few climatic parameters are considered by this method, thus it is a rather inaccurate and not so reliable method. Moreover it can yield to a result that is hard to interpret (similar to the case of isotherm modeling of Moesz line). Nevertheless, it is a very fast method and does not require digitizing distribution areas. Line modeling is a somewhat complicated method. It is based on modeling the shift of the distribution area of a fictive species, whose northern distribution borders coincide with the phytogeographical line (the southern border is irrelevant). It is a slow but somewhat more accurate method. The most complicated method is called Distribution modeling, which is also the slowest one. The model is run on the distribution of numerous plant species bound to the phytogeographical line separately. Then the northern borders of the predicted potential distributions are merged. The method provides detailed result, but drawing the final line (the prediction) is still subjective. Detailed comparison of the three aforementioned modeling methods is published by Bede-Fazekas (2012b). Distribution modeling is, in methodical terms, similar to multiple Line modeling.

Line modeling is a kind of Climate Envelope Modeling (CEM) which is about predicting responses of species to climate change by drawing an envelope around the domain of climatic variables where the given species has been recently found and then identifying areas predicted to fall within that domain in the future (Ibáñez et al., 2006, Hijmans and Graham, 2006). It assumes that (present and future) distributions are dependent basically on the climatic variables (Czúcz, 2010) which is somewhat dubious (Skov and Svenning, 2004).

36 climatic variables were used for the modeling: monthly mean temperature (°C), monthly minimum temperature (°C), and monthly summarized precipitation (mm). All the climatic data were averaged in the periods of thirty years.

RESULTS OF LINE MODELING

The results of Line modeling is shown in *Fig. 3.* The method was visually validated (by the correlation of the Moesz line and the modeled line for the reference period). Some measurements are also known for model evaluating, eg. Cohen's kappa (Cohen, 1960) and ROC/AUC (Hanley and Mcneil, 1982), they are, however, based on measuring areas instead of coincidence of curves. The observed precision is good enough despite of the relatively low horizontal resolution of the climate data. The modeled distribution of the

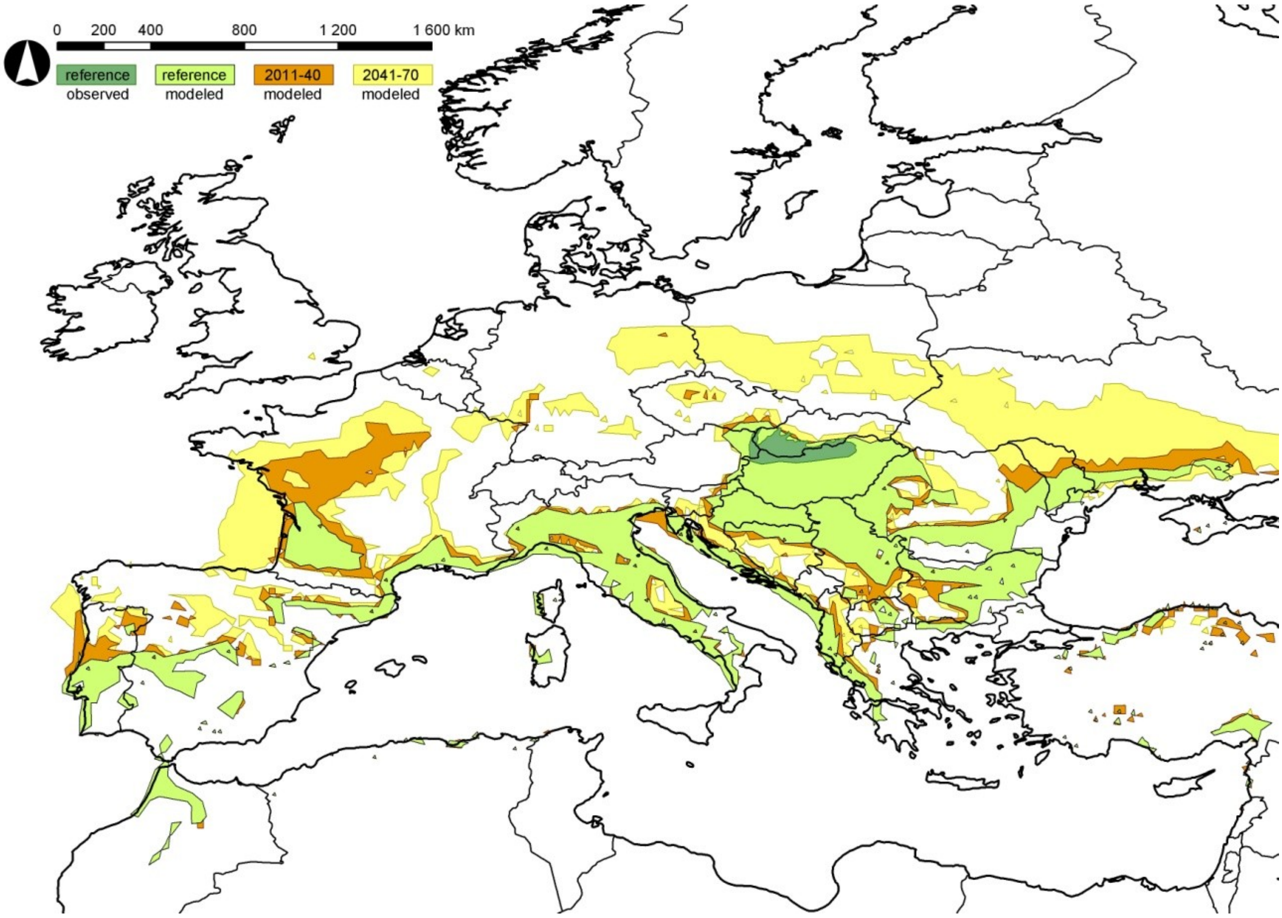

Fig. 3 Observed distribution, modeled potential distribution for the reference period, and predicted potential distribution for the future periods of the fictive plant species bound to the Moesz line in case of the Line modeling method

fictive species shows a northern border from Southern France, through the southern and eastern foot of the Alps, the southern foot of Western Carpathians, the western foot of the Eastern Carpathians, the southern and eastern foot of the Southern Carpathians, to Southern Ukraine. The prediction for the period 2011–2040 shows not such a great shift in the Carpathians as it was expected. Remarkable shift can be seen in France and to the east of the Eastern Carpathians. For the far future period (2041–70) the model provides results that correspond with our preliminary expectations. The predicted line displays in three segments separately: 1) the Moesz line may shift upwards (and northwards) to the Carpathians; 2) in Poland, a new Moesz line may appear, which indicates the northern border of the distribution of species that can be established in Poland; 3) and a southern border of the Polish territories of optimal climate (so called 'anti-Moesz-line') may appear in the northern side of the Carpathians. Besides the expansion in France, discrete territories in England, Belgium, Germany and Bohemia are also predicted for the far future period. *Fig. 3.* also points out that the Carpathians (and subordinately the Alps) will obstruct (as phytogeographical barrier) the expansion of the plant species bound to the Moesz line.

DISCUSSION OF THE IMPROVEMENT OF MODEL WITH ARTIFICIAL INTELLIGENCE ALGORITHMS

As the model results show, two of the three aforementioned modeling methods provide maps good enough (in terms of comparison of the observed and modeled distributions in the reference period) to display the impact of the climate change. Since only a few climatic parameters were applied, the accuracy and reliability of the model can be improved by using some other climatic parameters (eg. sum of heat, length of vegetation period, length of the period endangered by frost) and edaphic parameters (eg. alkalinity, quantity of lime). Although, more detailed and accurate inputs (eg. distribution maps, climate grid) could strengthen the model, it should also be noted, that the real improvement of the model can be reached only by the development of the modeling method.

The cumulative distribution function should be calculated by statistical software to leave some percentiles from the minimum and maximum values of a certain climatic parameter. Hence, only the climatic values that are bound exactly to the studied distribution area will be considered, since climatic extremes are mainly found near the distribution border will be left.

Further improvement of the abovementioned Line model can be applied by using statistical or artificial intelligence (AI) methods to select the appropriate parameters from the infinite combination of the numerous climate parameters objectively. Various ways can be used to determine the climate envelope, including simple regression, distance-based methods, genetic algorithms for rule-set prediction, and neural nets (Ibáñez et al., 2006). To reduce subjectivity of parameters' choice, logistic regression can be applied, which specifies the linear combination of climate parameters that determines the likelihood of distribution. Another appropriate statistic method is cluster analysis, which explains the vector of climate parameters as points of a multidimensional space, and searches for a lower dimension which separates the distribution apart its surroundings. Other clustering methods can be used, too.

In comparison to statistical methods, applying artificial intelligence algorithms may results in much more improvement of the model. Note, that some of them are black box methods, which can only answer the question what?/where?/when?, but not the question why?/how?. Several artificial intelligence methods can be used for modeling the distribution of plant species or phytogeographical units, such as decision tree, evolutionary algorithm, and artificial neural net (ANN). Hilbert and Ostendorf (2001) studied different forest types with ANN, and the research of Carpenter et al. (1999), Özesmi and Özesmi (1999), Hilbert and Van Den Muyzenberg (1999), Özesmi et al.(2006), Harrison et al. (2010), and Ogawa-Onishi et al. (2010) should be mentioned, since they modeled the distribution of species or communities with ANN. Evolutionary algorithm (which matches the climatic parameters with alleles and provides a process similar to natural selection with finite length) could conclude which parameters (and which extrema of them) are able to express the climate tolerance most of all. The result is therefore similar to the equations used in this research. This does not hold for ANN, since a complicated neural net cannot be reduced to linear mathematical expressions. ANN is similar to a real neural net densely furnished with axons, where the neurons are organized in layers. The algorithm has two main phases. Learning phase is the first, when the program builds up and balances the internal structure of the net in such a way, that it is adjusted to the distribution of the plant. After the learning phase the model could determine the likelihood of presence at all the points of Europe (for the reference period and the future periods, too).

In contrary to ANN, the aforementioned statistical and AI methods are not able to result in a map showing the potential distribution area (which is still the aim of modeling). On the other hand ANN is the only method among them which is not able to separate the filtering of climate demands of species apart from the prediction. The essence of the learning phase is that based on the distribution and climate data the program forms a multi-layered structure and it calculates the so called weights of every axon, iteratively. In the course of the time-consuming, but finite learning phase the weights are continuously changed based on remodeling and error evaluation.

A well parameterized ANN with appropriate topology could model the future potential distribution area in a much more reliable way. The feedforward neural network (with multilayer perceptron model) seems to be the most suitable for distribution modeling. An ANN with Backporpagation training method is now under development in Python programming language for

ArcGIS software. Input layer is connected to the climatic parameters (the number of neurons is determined by the number of parameters). The output layer has only one neuron which is able to predict a presence/absence data (1/0) or the likelihood of the absence (%). The training set is the part of the prediction set; the latter is the grid of the climate model (with more than 20,000 points).

CONCLUSION

The modeling approaches of the distribution of plant species and phytogeographical units were studied and the conspicuous deficiencies of them were discussed. Note, that in absence of AI supported modeling method, the used three simple models could provide spectacular results. Modeling the Moesz line yielded remarkable results, which are not perfectly the same as it was expected. It can be concluded that the Northern Carpathians will provide significant barrier for the plant species bound to the Moesz line. In harmony to the studies of Kovács-Láng et al. (2008) – who stated that the speed of ecological processes is not synchronous with the speed of the climate change and therefore the mountains with latitudinal direction may become natural barriers – we should note that without human aid some of these species will not be able to get as far as Poland. Hence there is a risk that the predicted shift of the Moesz line may be a prediction of the shift of only a virtual line.

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EVALUATION OF GROUNDWATER QUALITY USING WATER QUALITY INDICES IN PARTS OF LAGOS-NIGERIA

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Abstract

Water samples collected from forty-five hand dug wells and thirteen boreholes using random sampling technique were measured for pH, electrical conductivity and total dissolved solids. Calcium, chloride, bicarbonate and carbonates were analyzed using titrimetry method. Magnesium, potassium and sodium by Atomic Absorption Spectrophotometer (AAS) and sulfate was analyzed using a spectrophotometer. The study aims to evaluate groundwater quality using water quality indices in parts of Lagos-Nigeria. The sample locations and spatial variations in the concentration of bicarbonates, Revelle and Water quality indices were mapped using surfer 6.0 software. The result shows that pH indicate extremely acidic to strongly alkaline condition, EC shows medium and high enrichment of salts from location 28 and 21 respectively. Spatially, about 31% and 29.3% of bicarbonate are under poor and moderate zones respectively. The computed Revelle index shows that 41.4% and 1.7% are slightly and strongly influenced by groundwater salinization respectively. Unlike the water quality index, about 12.1% and 1.7% indicate poor and water unfit for drinking respectively. The paper concludes that groundwater salinization is on the increase since over half of the samples are influenced by salinity. Unlike the water quality, it was concluded that the water is of good quality since about 86.2% is suitable for drinking purposes. Based on these findings, it was recommended that waste water treatment and disposal methods should be avoided and appropriate treatment methods to make it more potable and fit for human consumption should be employed in critical locations of the study area.

Keywords: groundwater, Lagos-Nigeria, water quality, Revelle Index, Water Quality Index

INTRODUCTION

Fresh water, as a valuable and finite resource, is a central issue of sustainable development, economic growth, social stability, and poverty alleviation. Fresh water quality has grown to become the major international issue in recent years (Rejith et al., 2009). Urban growth, increased industrial activities, intensive farming, and overuse of fertilizers in agricultural production have been identified as drivers responsible for these changes (Patwardhan, 2003). Studies have shown that the polluted environment has a detrimental influence on human health, fauna and flora species (Sujatha and Reddy, 2003). Contamination of groundwater (resulting from human activities or from inherent aquifer material) impairs water sources and poses threat to public health (Renji and Panda, 2007). Rapid population growth and increased anthropogenic activities result in huge discharge and diverse pollutants reaching sub-surface water. Excessive groundwater withdrawals have been reported to result in hydro-chemical changes in the physical, chemical and microbiological water quality, decline of the water table, reverse hydraulic gradient and consequently water quality deterioration in coastal areas (Esteller et al., 2012; Jamshidzadeh and Mirbagheri, 2011). Poor water quality results in incidences of waterborne diseases and consequently reduces the life expectancy (WHO, 2006). Thus, concern for clean and safe drinking water and protection from contamination is justified because a large proportion of the population in the study area depends on sub-surface sources e.g. dug wells and boreholes etc. for domestic and drinking uses.

Water quality evaluation is based on the physical, chemical and biological parameters ascertaining the suitability for various uses such as consumption, agricultural, recreational and industrial use (Boyacioglu, 2007; Sargaonkar and Deshpande, 2003). Traditional methods of assessing water quality are based on the comparison of experimentally determined parameter values with existing guidelines. This method allows proper identification of contamination sources essential for checking legal compliance (Boyacioglu, 2007). One of the advantages of water quality index (WQI) is that it serves as a useful and efficient method for assessing the suitability of water quality for various purposes. It also serves as a mean of communicating information on the overall quality of water using a single number both temporarily and spatially (Christiane et al., 2009; Boyacioglu, 2007).

Water quality indicators have been applied to assess the overall water quality in different parts of the globe efficiently (Bharti and Katyal, 2011). These indicators are based on the comparison of water quality parameters using regulatory standards to give a single value to the water quality of a source. WQI computation involves four steps: parameter selection, development of sub-indices, assignment of weights and aggregation of sub-indices to produce an overall index. WQI helps to reveal the temporal and spatial variation of water quality (Bharti and Katyal, 2011). It also serves as a useful tool for summarizing large amounts of water quality data into simple terms such as excellent, good, bad, etc. for easy communication to the public.

Literature abounds on water quality assessment. Akoteyon et al. (2010), Yidana and Yidana (2010), Akoteyon and Soladoye (2011), Jamshidzadeh and Mirbagheri (2011), Partey et al. (2010), Celik and Yildirim (2006) Mishra et al. (2005), Edmunds et al. (2003) among others applied WQI in evaluating groundwater. For instance, Shah et al. (2008) compared groundwater quality in Gandhinagar Taluka in India and developped the water quality index for the area. Zaharin et al. (2009) classified salinization of groundwater in the shallow aquifer of a small tropical Island in Sabah, Malaysia using Revelle index (i.e. Cl / (HCO_3 + CO_3). Lobo-Ferreira et al. (2005), Chachadi and Lobo – Ferreira (2001) also adopted this index to evaluate seawater intrusion into the coastal aquifer in India. Thus, this study is aimed at evaluating groundwater quality using water quality indices in parts of Lagos-Nigeria as an alternative method for disseminating information on water quality status using indices for better understanding both by the public and relevant agencies.

STUDY AREA

The study area is located approximately between latitudes $6^o23'\ 30'^N$ and $6^o34'15^N$ and longitudes $3^o28'0^E$ and $3^o38'45^E$. It is bounded in the East by Ibeju-Lekki, in the North by the Lagos Lagoon and in the South by the Atlantic Ocean and parts of the metropolis in the West. The climate is tropical, hot and wet and the area is characterized by coastal wetlands, sandy barrier islands, beaches, low-lying tidal flats and estuaries (Adepelumi et al., 2009). The average temperature is about 27^0C with an annual average rainfall of about 1,532 mm (Adepelumi et al., 2009). The major seasons are the wet and dry seasons. The wet season lasts for 8 months (April to November) and the dry season covers a period of 4 months (December to March (Adepelumi et al., 2009). The dominant vegetation consists of tropical swamp forest (fresh waters and mangrove swamp forests and dry lowland rain forest).

The area is drained by Lagos Lagoon (Emmanuel and Chukwu, 2010). The geology is underlain by the Benin Formation and is made up of highly porous sand and gravel with thin shale/clay inter-beds (Oteri and Atolagbe, 2003). The groundwater flow direction shows a general North to South direction with two small cones of depression in Apapa and Ikeja because of intense groundwater extraction (Coode et al., 1997; Oteri and Atolagbe, 2003).

The hydrogeology is characterized by unfossiliferous sandstone and gravel weathered from underlying precambrian basement rock (Longe, 2011). It consists of Abeokuta and Ewekoro Formations, Coastal Plain Sands (CPS) and recent sediments. The CPS aquifer is the most productive and exploited aquifer in Lagos state. CPS is categorized into four types namely the recent sediments, the second and third aquifers also known as (upper and lower) CPS aquifer and the fourth aquifer is the Abeokuta formation (Longe, 2011).

The upper coastal plain sand aquifer (UCPS) is a water table aquifer and ranged from 0.4–21m below ground level with a relatively annual fluctuation below 5m (Asiwaju-Bello and Oladeji, 2001). This aquifer is usually tapped by hand dug well. The major limitation of this aquifer is that, it is prone to pollution because it is near to the ground surface. Unlike the lower coastal plain sand (LCPS) aquifer, it is tapped through boreholes.

MATERIALS AND METHODS

Fifty-eight samples including 45 hand dug wells (samples 1–45) and 13 boreholes (samples 46–58) were randomly selected for evaluation of groundwater salinization and quality assessment in the study area. Samples were collected in clean 150ml polyethylene bottles and preserved in ice chests for delivery to the chemistry department of the University of Lagos, Akoka for laboratory analyses using standard methods (APHA, 1998). In-situ parameters were measured for electrical conductivity (EC), pH and total dissolved solids (TDS) using a portable hand held (HI98303, Hanna model), (PH-102, RoHS model) and TDS/TEMP HM Digital model respectively. The *in-situ* measurements were necessary because these parameters are likely to change on transit to the laboratory. Chloride, calcium, carbonate and bicarbonate were determined using titrimetry method. Atomic Absorption Spectrophotometer (AAS) HI 98180 model was used to analyze magnesium, potassium and sodium, and sulfate was determined using spectrophotometer, HACH DR/2000 model. The individual sample co-ordinate and the computed Revelle and water quality indices were exported to the Surfer 6.0 software package for mapping the spatial variations of bicarbonate, the Revelle index and the water quality index using the Kriging method. The statistical analysis of the examined groundwater parameters were computed using SPSS software 17.0 version.

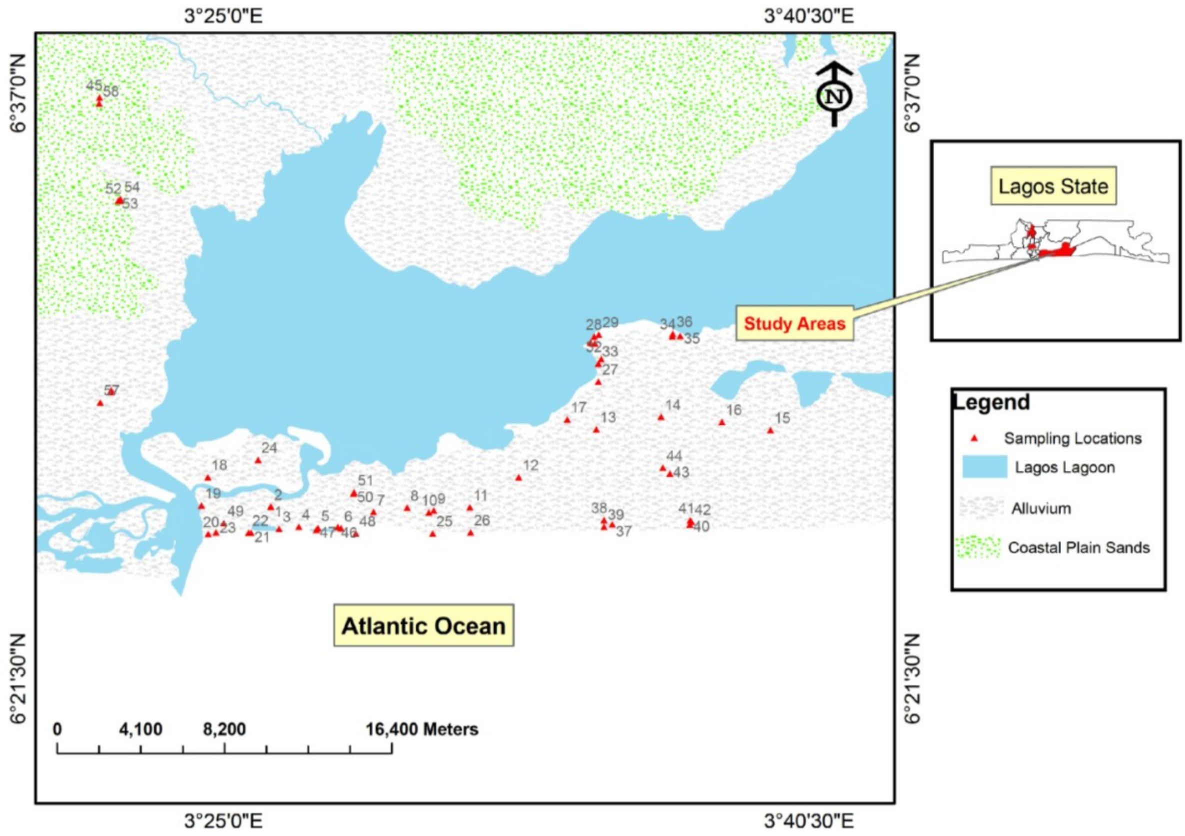

Fig.1 Sampling locations

Co-ordinates of the sampled wells were recorded using Global Positioning System (GPS) and thereafter were plotted using ArcMap 9.3 software on the geological map of Lagos, sheet 68 on 1:250,000 scale to generate a map of the sampling locations (*Fig.1*).

Evaluation of groundwater salinity and the drinking water quality assessment were executed applying:

Revelle Index (RI):

$$R = rCl^{-} / (rHCO_3^{-} + rCO_3^{2-}) \qquad (1)$$

where:

r = milliequivalents per litre (meq/l)

RI < 0.5 (unaffected), 0.5- 6.6 (slightly affected) > 6.6 (strongly affected) (Zaharin et al., 2009; Revelle, 1941)

The Water Quality Index (WQI) was evaluated using the World Health Organization (2004) standard. The stages of calculating the WQI include:

$$qn = 100\,[Vn - Vio\,] / [Sn - Vn] \qquad (2)$$

where:

n is the water quality parameter and quality rating or sub index (*qn*) corresponding to n^{th} parameter (i.e a number reflecting the relative value of this parameter with respect to its standard (maximum permissible value)

qn = Quality rating for the n^{th} water quality parameter

Vn = Estimated value of the n^{th} parameter at a given the sampling point

Sn = Standard permissible value of the n^{th} parameter

Vio =Ideal value of n^{th} parameter in pure water (i.e. 0 for all other parameters except pH and Dissolved Oxygen (7.0 and 14.6 mg/l respectively).

The Unit weight (Wn) is calculated by a value inversely proportional to the recommended standard value (Sn) of the corresponding parameter.

$$W_n = K/S_n \qquad (3)$$

where:

Wn= unit weight for the n^{th} parameters

Sn = standard value for the n^{th} parameters

K = constant for proportionality

The overall WQI is calculated by aggregating the quality rating with the overall WQI which is calculated by aggregating the quality rating with the unit weight linearly as:

$$WQI = \Sigma q_n W_n / \Sigma W_n \qquad (4)$$

RESULTS AND DISCUSSION

The measured parameters and the descriptive statistics of the groundwater characteristics of the study area are shown in *Table 1*. The pH of the sampled wells varied from 3.4 to 8.55 indicating an extremely acidic to strongly alkaline condition that may affect the taste (Todd and Mays, 2005).

Table 1 Detected parameters of groundwater and their descriptive statistics

Sample No.	pH	EC (µS/cm)	TDS (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	CO_3^{2-} (mg/l)
1	6.84	630	424	13.4	4.16	69	45	38	176	9	153
2	7.33	285	200	10.11	2.05	96	30	40	169	7	148.4
3	6.8	380	264	7.61	1.54	160	16	38	UDL	11	445.2
4	5.96	748	515	13.65	2.28	316	26	82	50.4	17	339.2
5	5.92	204	141	3.7	0.45	86	30	18	UDL	5	339.2
6	6.02	375	257	6.95	1.8	72	44	34	UDL	9	275.6
7	6.52	222	153	6.33	2.12	90	22	20	UDL	5	254.4
8	6.4	182	128	3.85	0.74	102	15	14	67.2	4	148.4
9	4.54	206	143	4.27	1.89	82	74	80	UDL	6	314.4
10	5.58	763	533	32.3	5.12	110	112	176	UDL	19	826.8
11	6.01	310	219	7.22	3.51	12	2	36	100.8	8	127.2
12	5.31	348	240	6.99	4.2	64	56	48	UDL	8	402.8
13	5.48	174	124	4.16	1.89	30	26	32	117.8	5	84.8
14	5.5	360	250	5.59	2.34	150	20	44	369.6	8	106
15	5.32	40	30	0.63	0.19	16	2	8	UDL	2	106
16	3.79	659	453	16.52	4.88	234	22	142	UDL	14	360
17	3.4	213	150	2.79	0.87	92	16	30	UDL	5	233.2
18	6.09	658	440	29.64	4.52	190	32	116	UDL	8	848
19	6.86	327	223	9.2	1.76	94	28	36	252	6	63.6
20	6.61	145	99	4.09	0.36	44	16	16	50.4	4	84.8
21	6.57	4040	6112	1080.1	52.32	1200	580	3400	184.8	1250	106
22	6.7	442	302	17.89	2.72	52	74	70	67.2	7	275.6
23	7.14	648	449	25.56	3.97	114	96	100	621.6	12	127.2
24	6.41	490	341	15.89	2.71	76	94	62	218.4	7	190.8
25	6.8	738	492	69.7	10.58	118	106	246	210	10	UDL
26	6.43	438	296	47.38	6.42	50	34	166	110	8	UDL
27	5.48	648	442	41.53	5.65	138	54	140	120	9	UDL
28	6.29	1575	1020	122.51	15.75	414	106	448	570	16	40
29	6.1	1053	705	112.42	14.63	328	86	374	456	14	26
30	6.67	806	537	104	16.3	406	92	356	380	12	38.5
31	5.48	318	202	5.27	3.12	138	26	40	104	8	29.7
32	5.89	369	242	3.4	2.42	140	24	16	86	6	UDL
33	6.03	611	400	32.69	4.78	142	74	114	140	9	UDL
34	6.39	790	541	38.24	5.17	184	16	130	240	12	UDL
35	5.34	425	290	22.6	4.15	144	8	75	128	4	UDL
36	5.61	490	305	10.46	5.2	100	12	114	104	6	UDL
37	6.5	472	296	31.88	4.58	108	26	120	70	9	UDL
38	5.09	68	47	1.3	0.5	12	2	8	UDL	2	84
39	6.03	191	125	9.8	1.35	22	6	6	UDL	2	96
40	6.3	115	81	6.2	0.17	14	4	10	UDL	4	42
41	6.22	63	44	2.6	0.48	38	12	32	UDL	4	48.4
42	8.55	103	72	3.6	4.8	60	10	46	UDL	8	28
43	5.9	676	479	52.7	8.12	202	26	176	130	10	UDL
44	5.64	201	134	24.6	6.18	196	48	166	146	10	UDL
45	8	116	59	4.31	0.28	46	UDL	16	0.08	4	UDL
46	6.2	312	240	5.21	2.7	88	34	20	30.4	5	276.4
47	6.02	289	154	6.53	1.9	76	38	26	26.4	4	344.8
48	6	403	301	8.35	3.5	81	42	31	28	6	398.2
49	6.8	175	137.5	8	2.15	6.4	2.3	17.1	149.05	11.7	UDL
50	7.1	210	147.4	26.3	12.25	22	10	11	48.23	5.4	UDL
51	5.9	185	132.8	20.2	10.5	3.1	1.1	25.8	43.4	12.3	UDL
52	6	70	23	30	5.2	UDL	UDL	23	31.2	45	UDL
53	6	72	22	30	4.8	UDL	UDL	25	30	43	UDL
54	6	70	23	31	4	UDL	UDL	22	33.1	44	UDL
55	5.4	66	66.9	2.2	1.2	2.1	0.77	11.6	29.5	1.2	UDL
56	5.3	50	46.9	2.2	1	2.1	0.77	8.4	29.15	0.2	UDL
57	5.4	66	66.9	2	1.6	2.1	0.77	11.6	25.2	0.6	UDL
58	6	52	23	1.3	UDL	24	UDL	5	UDL	1	UDL

UDL-Under detection limit.

Table 1 (cont.) Detected parameters of groundwater and their descriptive statistics

	pH	EC (µS/cm)	TDS (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	CO_3^{2-} (mg/l)
Min	3.40	40.00	22.00	0.60	UDL	UDL	UDL	5.00	UDL	0.20	UDL
Max	8.60	4040.00	6112.00	1080.10	52.30	1200.00	580.00	3400.00	621.60	1250.00	848.00
Mean	6.07	433.36	351.40	38.80	4.80	118.24	41.03	133.04	102.50	30.70	134.70
Std. Dev	0.80	563.66	794.12	141.60	7.38	172.73	78.67	446.28	139.20	163.20	187.71
Skewness	-0.27	4.88	6.93	7.23	4.99	4.63	5.86	7.13	2.11	7.58	2.08
WHO Std.	8.5	1000	500	200	10	75	30	200	300	200	300

Min-minimum, Max-maximum, Std. Dev-standard deviation; WHO-World Health Organization; Std-standard

The Electrical Conductivity (EC) varied between 40 and 4,040µScm^{-1} with a mean value of 433.36µScm^{-1}. According to the classification in Rao et al. (2012), samples from locations 1 to 20, 22 to 27 and 29 to 58 are of low enrichment of salts while location 21 and 28 depict medium and high enrichment of salts respectively. TDS varied between 22 and 6,112 mg/l with a mean value of 351.44mg/l. According to Todd and Mays (2005), the samples from locations 1 to 20, 22 to 27 and 29 to 58 are of the fresh water type while locations 21 and 28 depict the brackish water type. Calcium, Magnesium, Sodium and Potassium varied between under the detection limit to 1, 200, under detection limit to 580, 0.63 to 1,080.10 and under detection limit to 52.32 mg/l with a mean value of 118.24, 41.03, 38.77 and 4.82 mg/l, respectively (*Table 1*).

Carbonate, chloride, bicarbonate and sulfate varied between under the detection limit and 848, under the detection limit to 621.6, 5 and 3,400 and 0.2 to 1,250mg/l with mean values of 134.70, 133.04, 102.46 and 30.73 mg/l respectively. According to Stuyfzand (1989), the classification of chloride shows that about 46.6% of Cl in the samples accounts for fresh water while 37.9%, 8.6%, 5.2%, and 1.7% accounted for oligohaline, fresh-brackish, brackish and brackish-salt respectively (*Table 2*). The spatial variation of bicarbonate in the study area is presented in (*Fig. 2*). According to the WHO (2004) classification, the variation in HCO_3 concentration revealed that about 31% of the samples are under poor zone, 29.3% moderate zone and 10.3% good zone respectively.

Evaluation of groundwater salinization

The computed Revelle index varied from 0.05 and 14.62meq/l. The relationship between the ratios of $Cl/HCO_3 + CO_3$ indicates a strong positive linear relation with Cl concentrations (r = 0.94, p < 0.01). This linear relationship indicates the mixing of saline water and fresh groundwater (Zaharin et al., 2009). *Figure 3* shows the spatial variation of the extent of the groundwater salinization in the study area. About 56.9% of the samples (n = 33) were unaffected by salinity, 41.4% (n = 24) were slightly influenced and the remaining 1.7% (n = 1) was strongly influenced by salinity. Areas of critical concern include locations 21, 25-30, 33-37, 41-44, and 51-58 in the study area. Thus, effort must be made to curtail the current groundwater salinization in the area in order to ensure groundwater sustainability.

Assessment of drinking water quality

The suitability of groundwater quality for drinking purpose in the study area was determined using World Health Organization (WHO, 2004) guidelines. According to Sahu and Sikdar (2008), the computed water quality index (WQI) ranged from 15.27 to 550.97mg/l. The spatial variations in the samples revealed that about 37.9% of the sampled wells had excellent water quality and 48.3%, 12.1% and 1.7% indicate good, poor and water unfit for drinking respectively (*Fig.4*). Critical areas that require urgent attention include locations 9-10, 16-17, 21 and 28. Others are 12, 23, 25 27, 33 and 43-44. These locations pose a threat to human health and water resources management in the study area.

Table 2 Classification of Chloride in the study area (Source: Stuyfzand (1989))

Chloride Type	**Chloride (mg/l)**	**Sample Numbers**
Very Oligohaline	< 5	-
Oligohaline	30.0-150	(n=23) 5, 7–8, 15, 17, 20, 32, 38–40, 45–47, 49–58
Fresh	30-150	(n=26) 1–4, 6, 9, 11–14,16, 18, 19, 22–24, 27, 31, 33–37, 41–42, 48
Fresh-Brackish	150-300	(n=5) 10, 25–26, 43–44
Brackish	300-1,000	(n=3) 28–30
Brackish-Salt	1,000-10,000	(n=1) 21
Salt	10,000-20,000	-
Hypersaline	>20,000	-

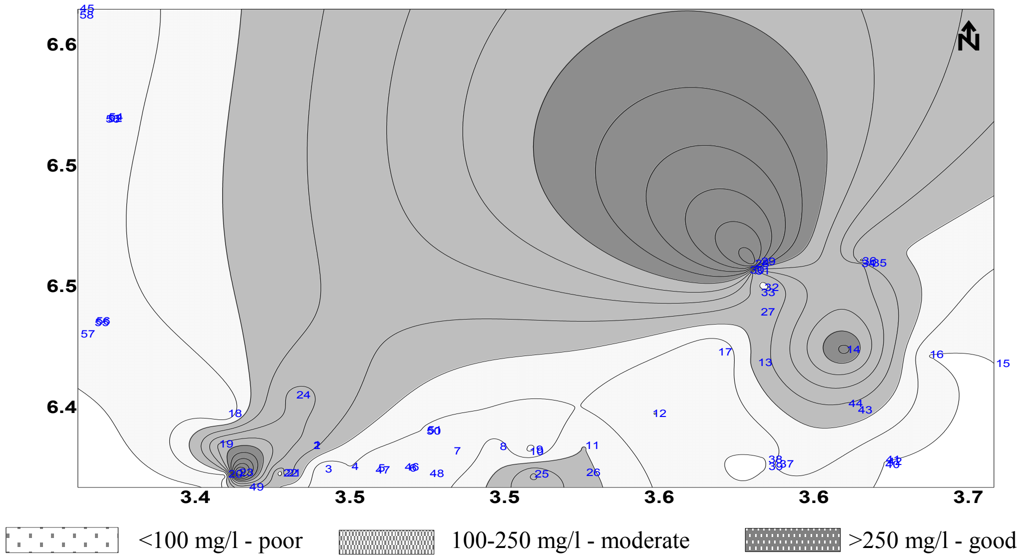

Fig.2 Spatial variation of bicarbonate

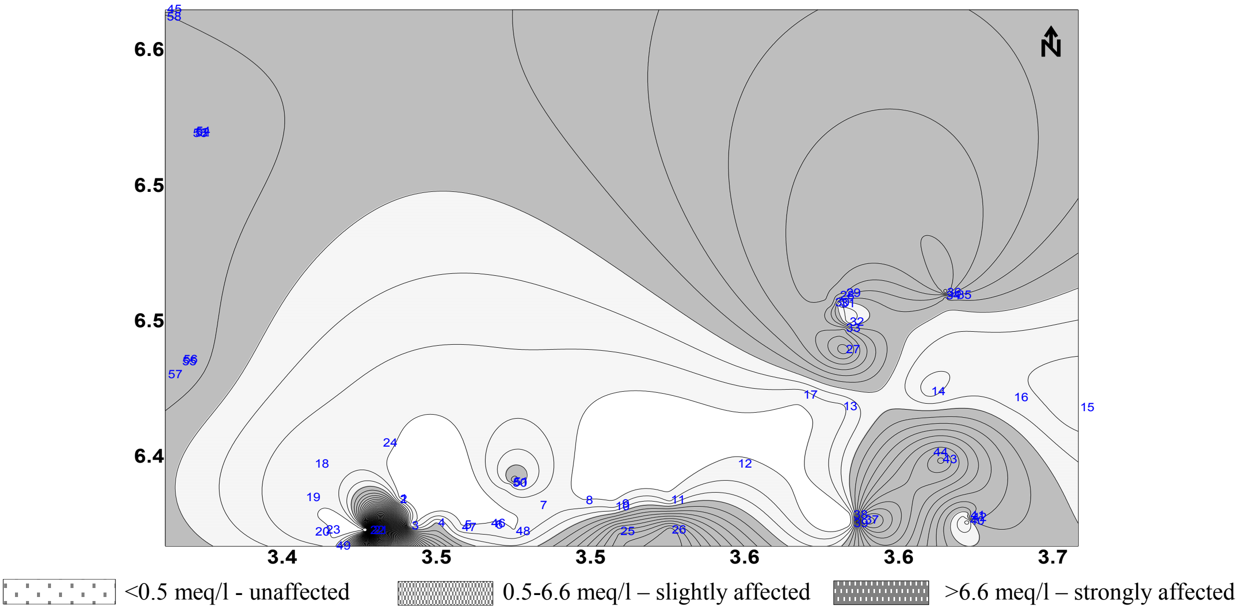

Fig.3 Spatial variation of Revelle index

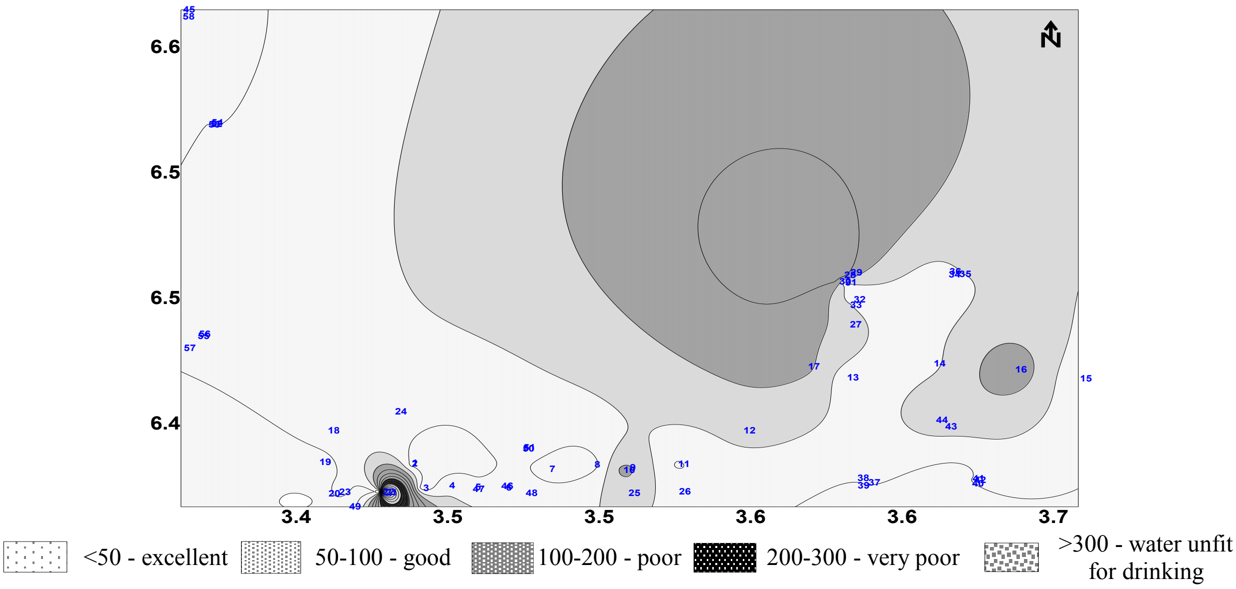

Fig.4 Spatial variation of Water quality Index

CONCLUSION

Groundwater is increasingly gaining significance as the main solution to the water supply problems in Nigeria, especially in the sub-urban and rural areas. The pH indicates extremely acidic to strongly alkaline conditions. About 96.6% of the EC values are characterized by low enrichment of salts, 12.1% medium enrichment of salts, and 1.7% high enrichment of salts. Major cations are in the order of: $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ and the major anions are in the order of: $CO_3^{2-} > Cl^{-} > HCO_3^{-} > SO_4^{2-}$. 46.6% of the samples accounts for fresh water and 37.9%, 8.6%, 5.2%, and 1.7% accounts for oligohaline, fresh-brackish, brackish and brackish-salt based on Chloride. Similarly, the classification of bicarbonate show that 31% of the samples fall under poor zone, 29.3% moderate zone and 10.3% good zone.

Groundwater salinization shows that 56.9% of the samples are unaffected, 41.4% are slightly influenced and 1.7% of groundwater was strongly affected. This infers that fresh groundwater contamination by salinity is a major concern for the fresh water supply in the study area especially around locations 21, 25-30, 33-37, 41-44 and 51-58. Thus, the need for the regulating groundwater exploitation through monitoring by concerned agencies for sustainable groundwater resource management. The suitability of groundwater for drinking purpose shows that about 37.9% of the samples had excellent water quality and 48.3%, 12.1% and 1.7% indicate good, poor and water unfit for drinking respectively. It is deduced that locations around 9-10, 16-17, 21 and 28 pose a great threat to water quality in the study area. However, the study concluded that the water quality of the study area is of good quality, since about 86.2% is suitable for drinking purposes. However, appropriate treatment methods to make it more potable and fit for human consumption should be employed in areas with poor quality. The study has contributed to knowledge by proffering methods of disseminating information on water quality status using indices for better understanding by the public and relevant agencies as well.

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ASSESSING LANDSCAPE SENSITIVITY BASED ON FRAGMENTATION CAUSED BY THE ARTIFICIAL BARRIERS IN HUNGARY

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Abstract

Artificial barriers significantly disturb the landscape unit. Roads split the contiguous landscape units, thus basically modifying their ecological characters. The more artificial barriers are constructed in the landscape, the more fragmented it is. Therefore, the contiguous landscape unit is divided into two or more patches, weakening resilience and stability of ecological systems. During decrease in patch size, the stability reduces until the patch size is at its minimum viable or effective population size. In current study analysing the degree of fragmentation caused by artificial barriers in meso-scale landscape units (meso-regions) we can get an overall picture about changes in their stability and sensitivity. The major aims of this study is to investigate the fragmentation of landscape units caused by three types of artificial barriers (roads, railways and settlements) in micro-regions, and to measure the degree of fragmentation and its spatial-temporal (1990, 2011 and future scenario to 2027) changes using mathematical/statistical analysis and landscape metrics (Number of Patches, Division, Landscape Splitting Index and Effective Mesh Size). By calculating landscape fragmentation metrics, the micro-regions are identified, which must be protected with high priority in the future. In the planning processes, type and position of artificial barriers could be more properly determined by calculation of these landscape metrics.

Keywords: landscape fragmentation, sensitivity, stability, artificial barriers, landscape metrics

INTRODUCTION

Landscape pattern embedded in the matrix is formed by patches and corridors (Forman and Godron, 1986; Formann, 1995). Ecological barriers as linear elements delimit landscape patches of similar ecological characters. Barriers can be categorized into natural (e.g. river -corridor) and artificial ones from the viewpoint of living being (Kerényi, 2007).

Artificial barriers (e.g. roads, railways, settlements) can significantly disturb the landscape unit. Roads and railways split the contiguous landscape units, thus basically modifying their ecological characters (Forman and Alexander, 1995; Trombulak and Frissell, 2000; Forman et al., 2003). They can result completely isolated patches, altering the ecological interactions between natural habitats (Harris 1984; Sauders et al., 1991; Forman, 1995).

Due to fragmentation the ecological stability deteriorates and the natural material and energy flow can be affected (Csorba 2005; Moser et al., 2007). Owing to the transport infrastructure (e.g. roads, railways) high concentration of pollutants is also emitted into the atmosphere, yielding change in micro-climate (Saunders et al., 1991; Reck and Kaule, 1993; Trombulak and Frissell, 2000; Spellerberg, 2002; Jaeger, 2002; Forman et al., 2003). The more than 20 m wide motorways exert significant influence on run-off and groundwater flow (Barta and Szatmári, 2010; Barta et al., 2011; Kun et al., 2012). Consequently, in the highly developed countries the fragmentation is considered as the most serious threat by which natural habitat is damaged (Jongman, 1995; Wascher and Jongman, 2000). The more artificial barriers are constructed in the landscape, the more fragmented it is. Therefore, the contiguous landscape unit is divided into two or more patches, weakening resilience and stability of ecological systems. During decrease in patch size, the stability reduces until the patch size is at its minimum viable or effective population size (size of isolated population which can survive with a given probability beyond a given period) (Gilpin and Soul, 1986). With the landscape fragmentation, the border length of landscape units increases, causing higher landscape sensitivity (Mas et al., 2010).

Analysing the degree of fragmentation caused by artificial barriers in meso-scale landscape units (meso-region) we can get an overall picture about changes in their stability and sensitivity. In the light of all this information, the major aims of this study can be summed up as follows: (1) to investigate the fragmentation of landscape units caused by artificial barriers in micro-regions, (2) to measure the degree of fragmentation and its spatial-temporal changes by mathematical/statistical analysis and landscape metrics.

DATA AND METHODS

The investigations of micro-regions were carried out on the whole territory of Hungary (Marosi and Somogyi, 1990 (*Fig. 1*).

Data

Change in the degree of fragmentation caused by artificial barriers was analysed based on time series data: between 1990 and 2010, future scenario was calculated to 2027.

Types of artificial barriers investigated in current study are the following:

- road network (motorways, highways, side roads)
- railway network
- borderline of inner-city area

During the fragmentation investigation, railways and roads were regarded as not only linear but average 2-dimensional elements (like 2-dimensional shape of settlements) (Fi et al., 2012; Megyeri, 1997) the average width of which are as follows:

- motorway = 26.6 m
- highway = 7 m
- side road = 3 m
- railway = 6.05 m

Similar to the settlements, these landscape elements, which cover an area determined by multiplying their width by length, represent "blind spot" for the natural wildlife. For example, 4.6 km^2 area of Danube-Tisza Interfluve is occupied by the M5 motorway between Budapest and Szeged (173 km) without entry and exit slip roads (173 km x 26.6 m). Therefore, the material and energy flow is the most modified in these areas, especially in their buffer zones.

- Data of 1990 as base year were originated from OTAB (1990) database on roads, railways and settlements.
- Data were available from GIS maps of Térkép Ltd. (1:100000) (Térkép Ltd., 2011) to evaluate the fragmentation in 2011.

For future scenario, county maps of the documentation „The long-term plans for development in Hungarian motorways and highways" (1222/2011.VI.29. governmental regulation) were applied (VI.29. governmental regulation). After the geo-referencing process, planned tracks on the maps until 2027 were digitized and finally digitized tracks were joined to the integrated network database (see below) (*Fig. 2*).

By comparing road network maps of databases established at different times, they proved not to be coherent; thereby most road sections that already existed in 1990 are not properly jointed to those in 2011. Besides, similar problem arose in the case of settlement networks, as well. All this can be explained with the absence of an integrated database containing the borderlines of inner-city areas in 1990 and 2011. During comparison of different databases, elimination of spatial inaccuracy is not easy. If we compare the sizes and locations of settlements in the studied period, territorial expansions can not always be attributed to urban sprawl.

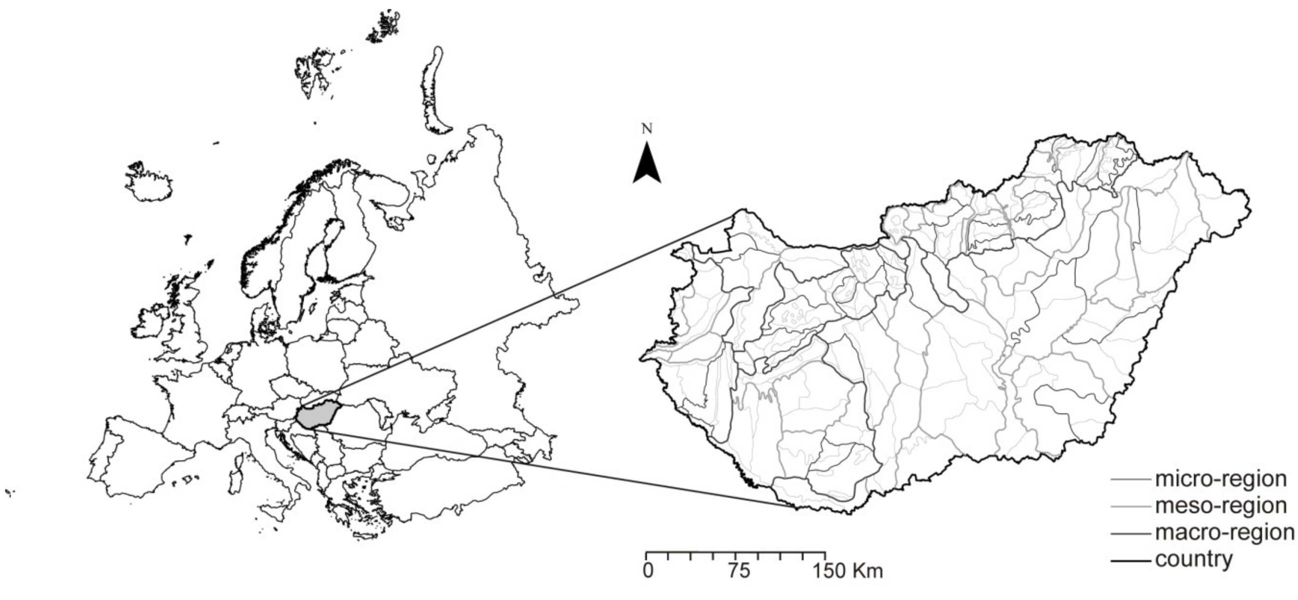

Fig. 1 Micro-regions of Hungary according to landscape delimitation in 1990

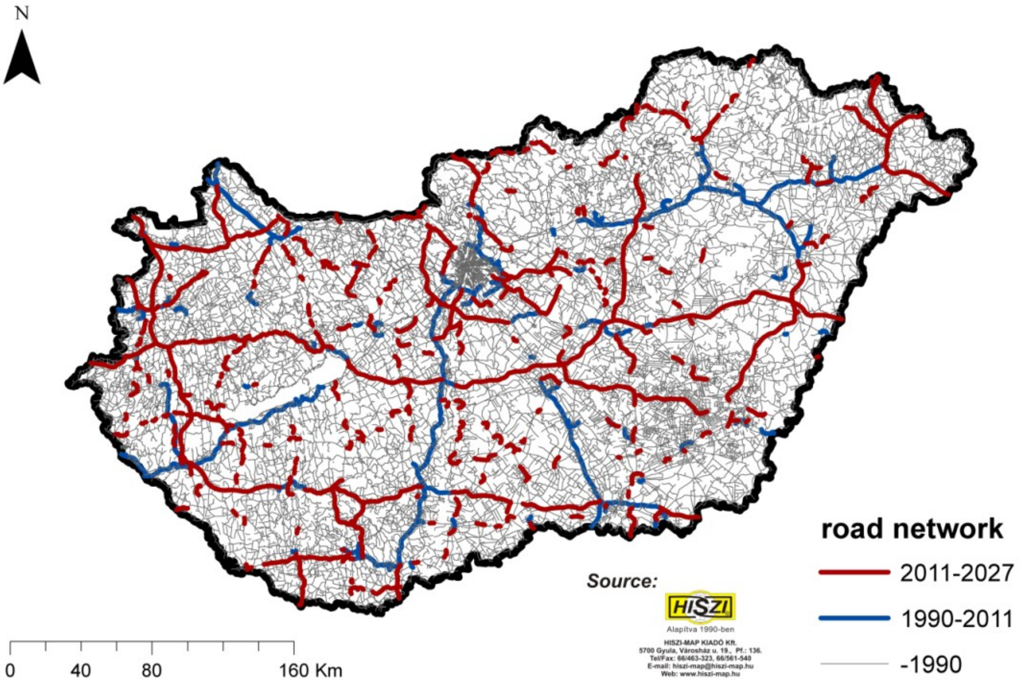

Fig. 2 Map on the expansion of road network between 1990 and 2027 based on the integrated road network database

These spatial errors may exert positive or negative influence on the fragmentation. In order to eliminate content inaccuracies an integrated road network database (based on network in 2011) was created in which the tables of attributes indicate road sections constructed prior to 1990 and between 1990 and 2011, respectively. With the help of this method, the error threshold has to be calculated exclusively in the case of settlements. During the tests, this value is 24.63 ha, which was counted as the average of size differences of settlements in two different basic databases.

Methods

The degree of fragmentation caused by artificial barriers can be measured in terms of various landscape metrics (McGarigal and Marks, 1995; Riitters et al., 1995; Haines-Young and Chopping, 1996; Hargis et al., 1998; Jaeger, 2000). Jaeger (2002) compared twenty-two landscape metrics to each other in order to find the most suitable one for fragmentation measurement. *Effective Mesh Size$_{CUT}$* (Mesh$_{CUT}$) proved to be the most adequate index. In addition, we counted three more metrics (*Number of patches, Division, Landscape splitting index*), which indicate the degree of fragmentation in different units. In each case, the metrics were calculated at class level; thus the patches and the classes are landscape units fragmented by artificial barriers as well as medium-scale landscape ecology units (~ micro-regions), respectively.

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Definition of landscape metrics indicating fragmentation:

- *Number of Patches* (NP): expresses the number of landscape units fragmented by artificial barriers. *Unit: pieces* (McGarigal and Marks, 1995).
- *Division* (D): is defined as probability that two randomly chosen living beings can not meet in the study area. *Unit: %* (Jaeger, 2000).

$$D = 1 - \sum_{i=1}^{n} \left(\frac{A_i}{A_t} \right)^2$$

where n: number of patches, Ai: size of n patches, At: total area of the region.

- *Landscape Splitting Index* (S): is determined as the number of patches one gets when dividing the total landscape into patches of equal size in such a way that this new configuration leads to the same degree of landscape division as obtained for the observed cumulative area distribution. *Unit: piece* (Jaeger, 2000).

$$S = \frac{A_t^2}{\sum_{n=1}^{n} A_i^2}$$

where n: number of patches, Ai: size of n patches, At: total area of the region.

- *Effective Mesh Size* (MeshCUT): denotes the size of patches when the landscape is divided into S areas (each of the same size) with the same degree of landscape division as obtained for the observed cumulative area distribution. Unit: ha or km^2

$$Mesh_{CUT} = \frac{A_t}{S} = \frac{1}{A_t}\sum_{i=1}^{n} A_i^2$$

where n: number of patches, Ai: size of n patches, At: total area of the region.

With the help of GIS data of Térkép Ltd. (2011) and OTAB (1990), maps of Coordination Center for Transport Development, these landscape metrics for each micro-region were calculated with respect to the railway, road network and settlements as artificial barriers for the year of 1990, 2011 and 2027.

Temporal changes in the fragmentation were also investigated in order to gain information on changes in landscape stability, sensitivity as well as potential landscape conditions in 2027 based on "The long-term plan and future development program of highway and motorway network" (1222/2011., VI.29. governmental regulation). In the case of change in MeshCUT index between 1990 and 2011 as well as probable further changes by the artificial barriers constructed in the micro-region until 2027, these landscape units can be supposed to have already modified material and energy flows after establishment of the artificial barriers *(Fig. 3)*. In contrast, in the future the examined parameters will not more change, thereby generating landscape balance (van Andel and Aronson, 2006).

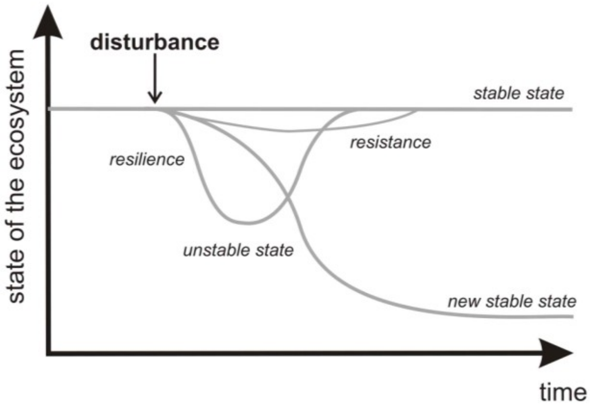

Fig. 3 Potential ecosystem responses to disturbance (e.g. construction of artificial barriers) (van Andel and Aronson, 2006)

RESULTS AND DISCUSSION

In order to get information on the sensitivity and the stability of landscape and its borders, temporal and spatial changes in fragmentation caused by artificial barriers (roads, railways, settlement) between 1990 and 2011 were determined calculating different landscape metrics. Moreover, the effect of motorway and highway networks to be constructed until 2027 on the landscape was studied. The micro-regions were examined which can be negatively affected by artificial barriers, reducing their stability and increasing their sensitivity.

Changes in the artificial barriers between 1990 and 2011

Almost 79% of the road network built between 1990 and 2011 is motorway (*Table 1*), which covers the largest area of landscape compared to other two barrier types. Furthermore, the entry and exit slip roads delimit landscape patches that have no ecological connectivity (~ residual patches) with each other or matrix (*Fig. 4*).

Table 1 Changes in the length of the road network between 1990 and 2011

	Sum length of track (km) 1990	Sum length of track (km) 2011	Change (km)
Motorway	953.99	3042.88	+2088.89
Highway	6791.79	7234.60	+442.81
Side road	53420.78	53535.45	+114.67
Sum:	61166.34	63812.93	+2646.37

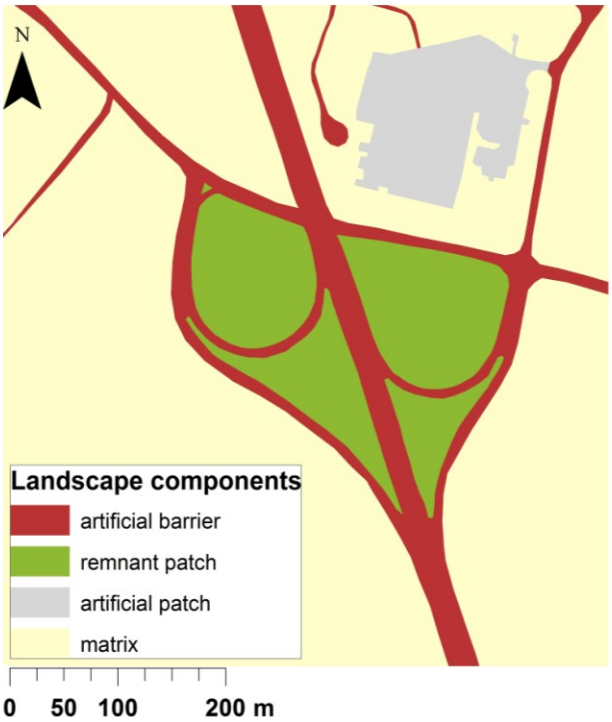

Fig. 4 Landscape components close to Kiskunfélegyháza after the construction of entry and exit slip roads at the M5 motorway

Beside motorways, mostly highway bypasses were constructed around the settlements in the study period. These bypasses (*Fig. 5*) are regarded to have the most significant fragmentation since their shapes can be not only straight but curved (their characters are similar to the entry and exit slip roads of motorways). Connecting to an existing road (with both start and end points), they are constructed mainly outside borderline of the inner-city area. Therefore, they are more likely to delimit a part of the landscape than a long straight road.

At the time of study period (1990-2011) Hungarian railway network are not extended by new tracks, whereas the existing ones are modernized as well as new stations are also built (Development of railway tracks, 2011). Therefore, this type of artificial barriers has not made the landscape more fragmented. Despite the fact that railway transport was liquidated in some sections, these sections can act as artificial barriers.

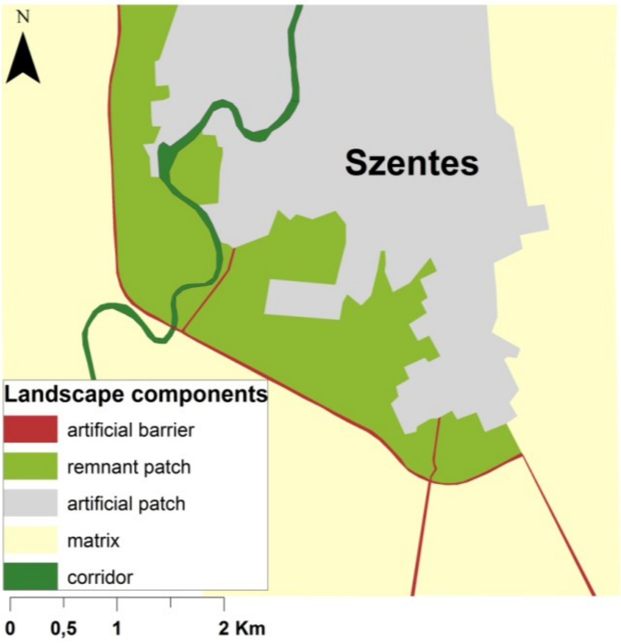

Fig. 5 Landscape components after the construction of bypass in Szentes

With regard to the error threshold, in the study period the most intensive territorial expansion was registered in the following Hungarian settlements (in descending order): Miskolc, Érd, Debrecen, Győr and Tiszaújváros. In addition, it was 12 cities in Hungary that exceeded 10 km^2 in the study period.

Change in fragmentation of micro-regions due to artificial barriers between 1990 and 2011

S, D, $Mesh_{CUT}$ metrics, except for NP, have been developed over the past decades (Jaeger, 2000; Moser et al., 2007), providing additional information on fragmentation and sensitivity of landscape compared to conventional metrics (Jaeger, 2002).

NP is the most common index of fragmentation. In the years 1990-2011, change in NP index was not determined in the case of 105 micro-regions, whereas this index increased in the case of 92 micro-regions. In terms of this index, fragmentation is the most considerable in the following micro-regions (in descending order): Pest Plain (+99) (*Fig. 6, No. 1*), Tolnai Sárköz (+66) (*Fig. 6, No. 2*) Middle Mező-föld (+64) (*Fig. 6, No. 3*), Sajó-Hernád Plain (+52) (*Fig. 6, No. 4*), South Baranya Hill (+45) (*Fig. 6, No. 5*).

After the establishment of a new linear element in transport network, this element can cross the existing ones in the landscape, cutting a patch out of the original landscape unit. NP unambiguously indicates this degree of fragmentation but can not give more information on characters of fragmentation and its adverse effects. As there has no been change in number of equal-sized patches defined with same probability, this index reflects no fragmentation in the case of 54 micro-regions (*Fig. 6*).

As far as S index is concerned, the five most fragmented micro-regions are: Győr-Tata Terrace Land (+12.33) (*Fig. 6, No. 6*), Middle Nyírség (+9.4) (*Fig. 6, No. 7*), Sajó-Hernád Plain (+9.01) (*Fig. 6, No. 4*), South Baranya Hill (+8.82) (*Fig. 6, No. 5*), Moson Plain (+8.12) (*Fig. 6, No. 8*). Consequently, results of the S index are partially congruent with those of NP index since Sajó-Hernád Plain and South Baranya Hill are the most fragmented micro-regions in terms of both metrics.

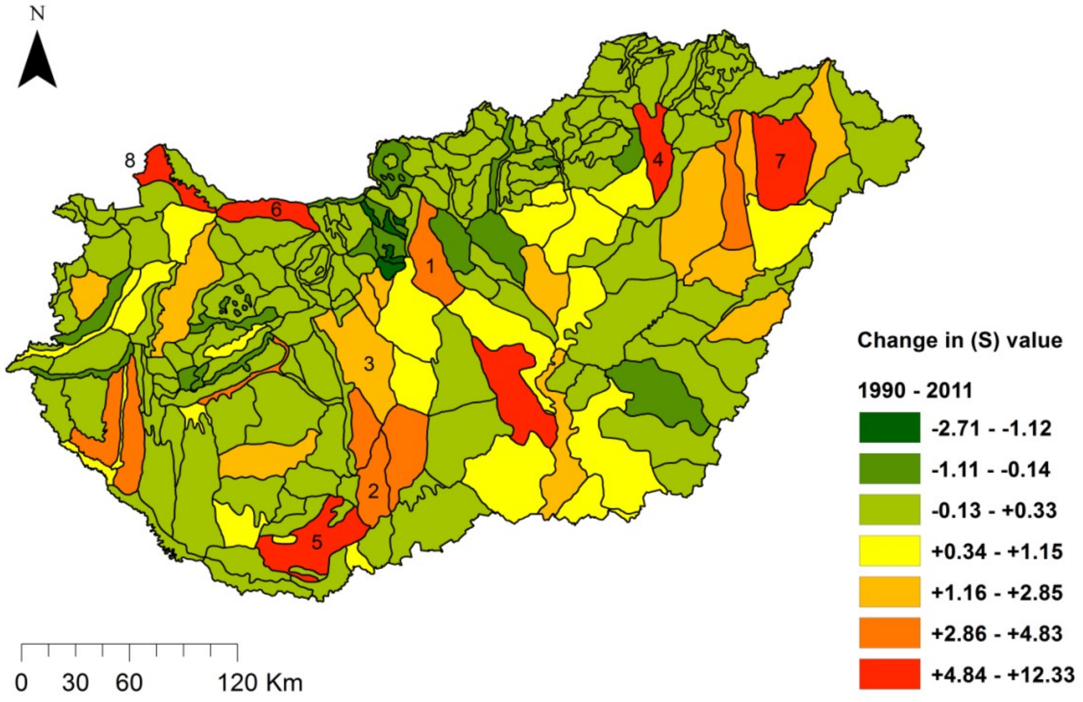

Fig.6 Change in Landscape Splitting Index (S) within micro-regions between 1990 and 2011 (based on fragmentation due to the artificial barriers)

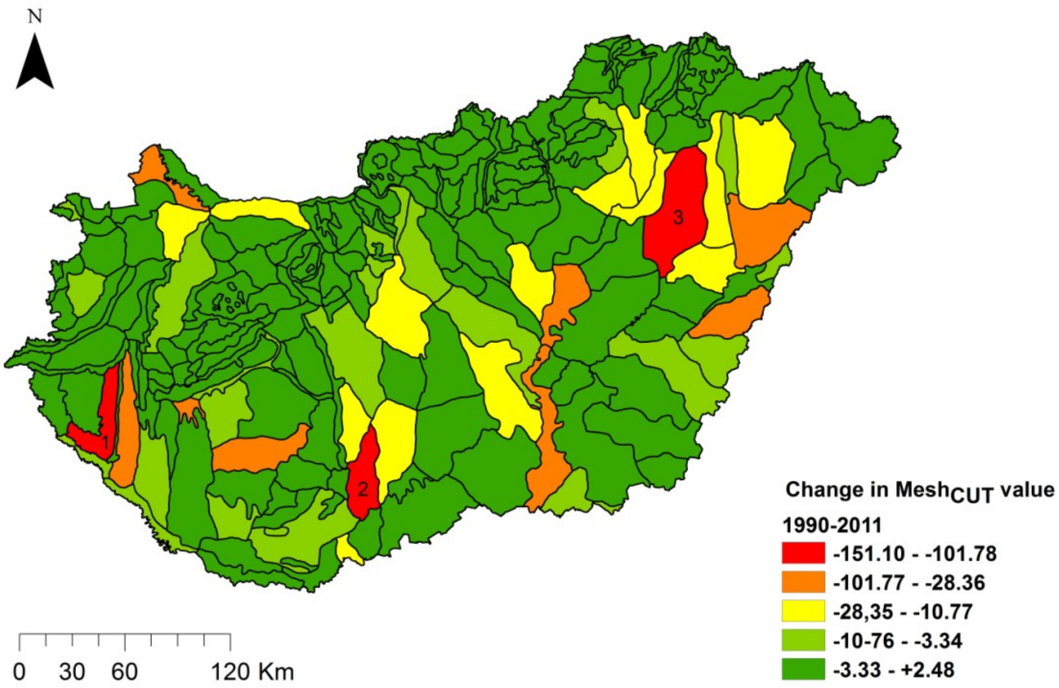

Fig. 7 Change in $Mesh_{CUT}$ index within micro-regions between 1990 and 2011 (based on fragmentation due to the artificial barriers)

The degree of fragmentation can be presented according to a specific example: In Győr-Tata Terrace Land (*Fig. 6, No. 6*), NP index was 11.74 and 24.07 in 1990 as well as 2011, respectively. Therefore, nearly twofold increase in this value indicates very severe fragmentation caused by artificial barriers in this micro-region. In other words, due to nearly 10 km long M1 motorway section bypassing Győr and urban sprawl of some cities (Győr, Tata, Komárom), this micro-region needs to be subdivided into twice as many equal-sized patches in order that two living beings can meet within the study area.

Change in $Mesh_{CUT}$ index during study period can be seen in the Fig. 7 with special regard to error threshold, no change in $Mesh_{CUT}$ can be noticed in the case of 54 micro-regions.

Considering effectively usable habitat, Egerszeg-Letenye Hill (*Fig. 7, No. 1*) can be considered to have the most unfavourable conditions (*Table 2*). $Mesh_{CUT}$ index reveals that this micro-region's total area of 645.02 km^2 decreased by 155.93 km^2. Owing to the highway 74, which cuts the micro-regions into two pieces in the north-eastern, and a section of the M7 motorway between Nagykanizsa and Letenye, NP, S and D metrics have increased from 18 to 45, from 2.56 to 7.15 as well as from 61 to 86, respectively. Therefore, the degree of fragmentation caused by artificial barriers is so serious here that the transport network development should be avoided in the future. If it is not possible, then road designers have to pay more attention to the ecological corridors of suitable quality and wide (ecoducts), which in optimal case facilitate faunal and floral migration between artificial objects.

$Mesh_{CUT}$ index demonstrates that the territory of more two micro-regions has decreased by 100 km^2 (*Table 2*). Landscape elements fragmenting micro-region Tolna Sárköz (*Fig. 7, No. 2*) are the followings: the M9 and M6 motorways cut this micro-region into two pieces in the east-west as well as the north-south direction, respectively.

Landscape elements fragmenting micro-region Hortobágy (*Fig. 7, No. 3*) are the following: a section of the M3 motorway between Polgár and Hajdúnánás (55 km); the highway 35 towards Hajdúböszörmény connecting to the motorway in the middle of the micro-region; a bypass situated in the eastern part of settlement Polgár (*Fig. 8*).

Table 2 Landscape metrics of the three most fragmented micro-regions between 1990 and 2011

Name of the micro-region	Change in NP (Pcs.)	Change in S (Pcs.)	Change in D (%)	Change in $Mesh_{CUT}$ (km^2)
Egerszeg-Letenye Hill *(Fig7. , No. 1)*	+27	+4.59	+25.08	-155.1
Tolnai-Sárköz *(Fig7. , No. 2)*	+62	+3.83	21.24	-133.74
Hortobágy *(Fig7. , No. 3)*	+19	+1.54	6.15	-101.78

Nevertheless, increase in the $Mesh_{CUT}$ index can also be observed in the case of 24 micro-regions. The maximum and average of this increase are 247.79 km^2 as well as 75.23 km^2, respectively. The first cause of increase in this index is the territorial expansion of settlements as a result of which they have reached the road network, in some case they have spread beyond it. Therefore, the NP and $Mesh_{CUT}$ metrics have decreased and increased, respectively owing to the modified shape of habitats. The second and third causes of increase in the $Mesh_{CUT}$ index are decrease in size of some settlements between

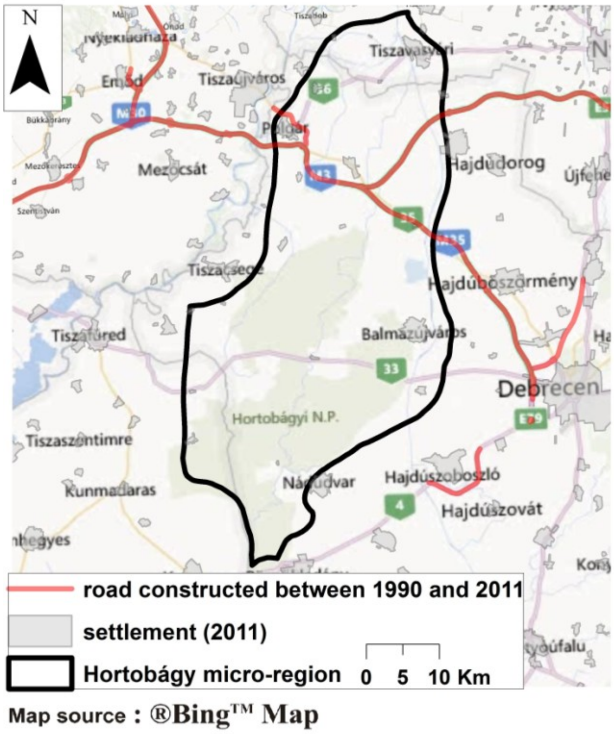

Fig. 8 New roads causing fragmentation in Hortobágy micro-region

1991 and 2011 as well as synergy of the first and second cases, respectively. It is unambiguous that reduction of the road and railways network is not responsible for the above-mentioned in the study period.

Consequently, further detailed studies are needed in the case of the concerned micro-regions in order to identify causes of this phenomenon.

Change in fragmentation of traditionally defined micro-regions due to artificial barrier between 2011 and 2027

If the long-term road development plan is fully implemented, 490.48 km more motorways (18.53%) and 2706.52 km more highways are to be constructed from 2011 till 2027. However, the plans have not included the construction of side roads (Table 3).

According to the scenario to 2027, NP index will not increased, thus the fragmentation caused by artificial barriers can not be predicted in the case of 67 micro-regions. Based on S index, fragmentation can not be assessed in 82 micro-regions, thus number of equal-sized patches, in such a way that this new configuration interprets to the same value of probability, will not increase. The following five micro-regions are likely to be the most fragmented in the future: Northeast Nyírség (+18.74) (*Fig. 9, No. 1*), Upper Kemeneshát (+10.09) (*Fig. 9, No. 2*), Bácska Loess Plain (+9.68) (*Fig. 9, No. 3*), Hatvan Plain (+7.87) (*Fig. 9, No. 4*), Szolnok Túr Plain (+7.12) (*Fig. 9, No. 5*).

Table 3 Changes in the length of road network between 2011 and 2027

	Sum length of track (km) 2011	Sum length of track (km) 2027	Change (km)
Motorway	3042.88	3533.36	+ 490.48
Highway	7234.60	9941.12	+ 2706.52
Side road	53535.45	53535.45	0
Sum:	63812.93	67009.93	+2646.37

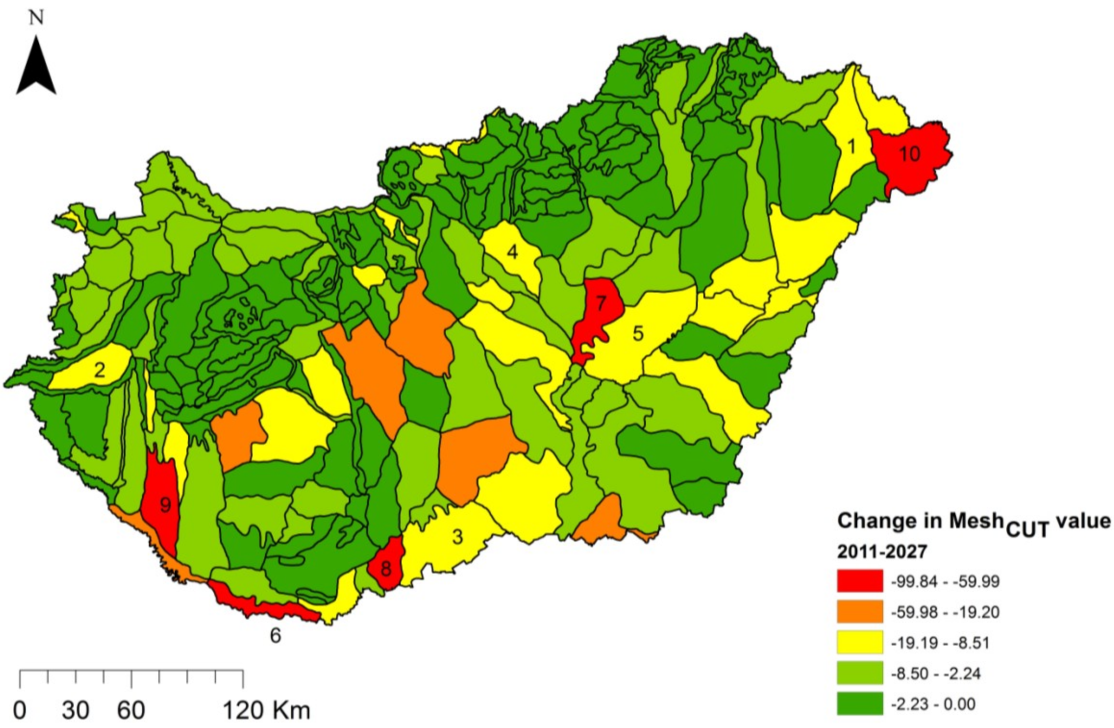

Fig. 9 Change in Mesh$_{CUT}$ index within micro-between 2011 and 2027 (based on the fragmentation due to artificial barriers)

Table 4 Landscape metrics of the five most fragmented micro-regions between 2011 and 2027

Name of the micro-region	Change in NP (Pcs.)	Change in S (Pcs.)	Change in D (%)	Change in $Mesh_{CUT}$ (km^2)
Dráva Plain *(Fig 9., No. 6)*	+2	+1.56	+24.42	-99.84
Szolnok Floodplain *(Fig 9., No. 7)*	+12	+5.26	+14.43	-86.23
Mohács Island *(Fig 9., No. 8)*	+3	+1.47	+24.45	-85.41
Western-Inner-Somogy *(Fig 9., No. 9)*	+9	+2.77	+10.01	-75.58
Szatmári Plain (*Fig 9., No. 10)*	+7	+7.07	+5.81	-59.99

After implementation of the long-term road development plan, $Mesh_{CUT}$ index of 101 micro-regions remain unchanged. In this aspect, Dráva Plain (*Fig. 9, No. 6*) can be regarded as the most disadvantageous micro-region in the future (*Fig. 9*) since its total area (433.27 km^2) will decrease by mostly 100 km^2 (99.84 km^2) due to a highway to be constructed from Sárvár to south border. This micro-region will be divided into two pieces in the north-south direction by new highway. Therefore, D index will increase from 46.43 % to 70.85 %.

In the case of three micro-regions, the $Mesh_{CUT}$ index decreased by more than 100 km^2 over the period 1990-2011, whereas in 2027 based on scenarios lesser decrease can be predicted. However, the non-negligible fact is that four more micro-regions are supposed to suffer a reduction of more than 50 km^2 (*Table 4*).

In the future, we have to lay greater emphasis on landscape ecological study of these micro-regions if all the planned roads are built. As far as the sensitivity of micro-regions is concerned, the most optimal would be if road designers took notice of not only the location of conservation areas under “Natura 2000” but reduction of landscape fragmentation for living beings based on calculation in current study. Consequently, more detailed landscape studies are necessary in the concerned micro-regions.

The sensitivity and stability of micro-regions fragmented by artificial barriers

In accordance with above-mentioned, it is obvious how the landscape fragmentation was changed by artificial barriers in a historical period (1990-2011) and how it will be modified in the future (2011-2027) after long-term road plan implementation.

So as to evaluate the sensitivity and stability of landscapes, two time-periods (1990-2027) were merged and analysed together. Four groups of the micro-regions can be differentiated based on their $Mesh_{CUT}$ metrics (*Table 5, Fig. 10*):

1. *Sensitive, mostly endangered, unstable micro-regions* the fragmentation of which has changed in both periods.
2. *Potentially sensitive micro-regions* the fragmentation of which did not change in the past, but they can be divided into smaller units due to the road development plans in the future.
3. *Potentially more stable micro-regions* the fragmentation of which changed in the past, but they are assumed to have no further fragmentation after the road development implementation.
4. *Stable micro-regions with minor sensitivity* the fragmentation of which did not change in the past and they are expected to have no fragmentation in the future.

Table 5 Classification of micro-regions in Hungary according to their sensitivity and stability

	Group 1	Group 2	Group 3	Group 4
Number of micro-regions (Pcs.)	129	15	46	40
Sum Area ($km^{2)}$	67588.8	5229.08	14381.8	5826.31
Sum Area (%)	72.66	5.62	15.46	6.26

1: In general, more than half of the micro-regions (129 of 230) have been divided into smaller units by artificial barriers in both study periods; they are most susceptible to external effects. Habitats are shrinking due to landscape elements built relatively quickly; the different landscape damaging processes (e.g. new road constructions) have not completed yet, resulting more and more sensitive and unstable landscape. Nonetheless, owing to data shortage the urban sprawl, which perhaps can reduce natural habitats, has not involved in current study.

2: 15 micro-regions were not fragmented by artificial barriers in the past, but they will be influenced in term of the road development plans up to 2027. Average value and maximal decrease of the $Mesh_{CUT}$ index are 3.3 km^2 as well as 11.7 km^2, respectively.

3: 46 micro-regions are supposed to be more stable in the future since they are likely not to been fragmented (from optimistic aspect, if further road network expansion is not planned and there is be no urban growth).

4: 40 micro-regions can be considered to be in the most optimal conditions as they will not be divided into smaller units from 1990 to 2027. As a matter of fact, this is an optimistic viewpoint if no more road networks were planned and the urban sprawl was not more intense in the future. Based on the test methods and data, these landscapes are in most stable conditions and are the least sensitive.

This classification addresses that the units in groups „1”, and „2” must be protected with high priority. It is greatly recommended to minimize fragmentation in these micro-regions during the practical landscape planning.

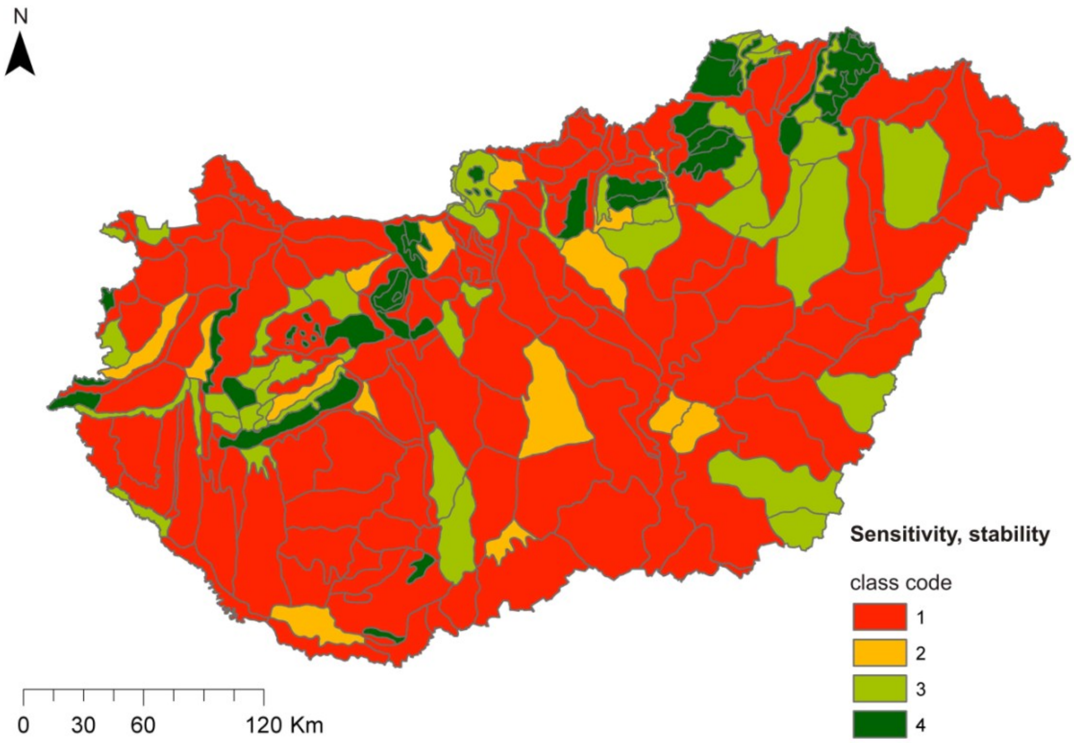

Fig. 10 Classification of micro-regions based on their sensitivity and stability to artificial barriers using data of 1990, 2011 and 2027

The landscape instability could be more effectively mitigated if not only the „Natura 2000" areas were prioritized, but the above-mentioned landscape metrics were also taken into account during the road development planning.

In the planning processes, type and position of artificial barriers could be more properly determined using the presented landscape metrics. Moreover, suggestions could also be made about micro-regions the balance of which can not tolerate more external effects (Girvetz et al., 2008; Jaeger et al., 2007; Fu et al., 2010). To realize all this, however, further analysis and various data are required.

Besides, the classification also calls for tasks to raise the stability and reduce the sensitivity in the case of micro-regions in groups „3" and „4". More ecological corridors suitable for "green belts" should be designed so as to achieve these goals.

CONCLUSIONS

The landscape is known to be a system in which the external effects can trigger instability and induce changes. The landscape sensitivity is interpreted as a rapid response to external effects, reflecting the conditional instability of the landscape system. The more artificial barriers are constructed, the greater fragmentation is, and thereby causing decrease in effective territory.

As a matter of fact, there are a lot more artificial barriers in the landscape beyond examined ones, but present study aimed to investigate the artificial barriers, which can be rapidly constructed and have a most negative impact on the landscape. Natural barriers could also be examined via the applied methods but artificial ones take more effect on landscape sensitivity thank to their "sudden" devastating impact in contrast to "slowly appearance" of natural ones.

In this study, the spatial and temporal changes in fragmentation caused by artificial barriers were analysed so as to estimate the sensitivity and stability of the ecosystem and landscape units. The artificial barriers (e.g. roads, railways, settlements) can lead to extensive landscape modification. The contiguous landscape units are divided by roads and railways, thereby resulting profoundly transformation in their ecological processes. The ecological instability arises in the fragmented subunits and material and energy flow is modified owing to fragmentation. Moreover, the contiguous landscape unit is divided into two or more patches, changing its ecological stability.

Different landscape metrics were calculated and together evaluated to determine the degree of fragmentation caused by artificial barriers (NP, D, S, $Mesh_{CUT}$ metrics). By comparing the degree of fragmentation in 1990 and in 2011, comprehensive view on the changes of landscape sensitivity are available now, whereas by involving data of long-term road development plan (up to 2027) into our research some scenarios can be demonstrated, as well.

The presented examples also clearly show that study of the numbers and extension of artificial barriers, the NP index has not provided enough information on fragmentation. If data from more periods are available, it is preferable to apply together three metrics (D, S, $Mesh_{CUT}$ index), which express the degree of fragmentation by different units, thus providing more information on temporal change in landscape sensitivity and stability.

Using $Mesh_{CUT}$ index, traditionally defined landscape units were categorized into four groups according to their sensitivity and stability based on data between 1990 and 2011, as well as between 2011 and 2027. Group 1 represents landscapes that are characterized by more sensitivity and a gradual loss in habitat stability due to the expansion of the artificial barriers. Some landscape units (Group 2) may only be sensitive in the future, others (Group 3) may be heading for a more stable future and there are some landscapes (Group 4) that were not and will not be affected by fragmentation caused by the artificial barriers.

The advantage of the applied method is that landscape metrics are considerable help in choosing the location of artificial barriers. Furthermore, it would be relevant to give some suggestion about landscape units the balance of which can not tolerate more such barriers. (Girvetz et al., 2008; Jaeger et al., 2007; Fu et al., 2010) To realize all this, however, further analysis (Kevei-Bárány, 2010) and various data are needed, for example land cover maps (Mucsi et al., 2007; Szilassi and Bata, 2012), national ecological network data (Tóth 2006), field measurement data (habitat mapping) (Czúcz et al., 2008), monitoring data on effectiveness of wildlife crossings using ecoducts (Hardy et al., 2003).

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ESTIMATION OF TOURISM CLIMATE IN THE LAKE BALATON REGION, HUNGARY

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Abstract
Lake Balaton is one of the most important and best-known tourist destinations in Hungary. Although in the last few years, several efforts were implemented to increase the length of the tourist season, the highest visitor turnover occurs in the summer months. We mostly regard the Lake Balaton as a bathing place, despite of the fact that the region offers more and more tourism products. The beach tourism and other lakeside activities are highly dependent on weather and climate. In order to know that a region's climate what extent is suitable to the given tourism activities, the tourism climate potential must be determined. This study aims to illustrate observed changes of the tourism climate potential of Lake Balaton Region during the last half century, by using Tourism Climatic Index (TCI) and Climate-Tourism-Information-Scheme (CTIS). The analysis is based on the long-term measured datasets of Siófok synoptic station. Based on the TCI, the tourism climate potential of the examined region is barely changed over the past 50 years; significant changes can be detected only in February and June. By using the CTIS, smaller changes can also be detected. Such changes are: moderate improvement of the thermal comfort in spring and autumn, slight increase in sunny hours in the tourism season, as well as the sultriness becomes more frequent in the summer months. The results may represent useful background information to the policy decision-makers.

Keywords: tourism climatic index, climate-tourism-information-scheme, tourism climatology, climate change, Lake Balaton

INTRODUCTION

Despite of the economic crisis, tourism is one of the major economic sectors in Hungary. In 2011 tourism produced 1115.7 billion Hungarian forints (about 5.1 billion USD) revenue, which means second-third place in industry-wide comparison. The contribution to the gross domestic product (GDP) is approximately 6%. In addition, more than 8% of the all employees are working in tourism sector. The Lake Balaton Region plays an important role in Hungarian tourism. The Lake Balaton or as the Hungarians call it, the "Hungarian Sea", is the largest fresh water lake in Central Europe with significant lakeside tourism. The southern shore of Balaton is ideal for small children because of the shallow water, but on the north shore the water gets deep faster. In summer the water temperature is around 26 °C, which is warmer than the average air temperature in the morning and in the evening. It can be said that the water and the climate are the main attractions of this region. According to Kéri (1974), meteorological point of view this means that if the weather does not hamper the tourists for enjoying the water, they do not even realize that the weather is good. The weather, as a factor, comes to people's mind when it goes wrong.

The weather and the climate is a key factor in tourism (Perry, 1997). There are multiple interactions between tourism and climate systems. First, the weather and climate can be *limiting factor in tourism* (de Freitas, 2003; Matzarakis, 2006). All regions have a tourism potential and appeal determined by the weather and climate. If a region's climate is optimal for tourism, the area has great appeal (*Fig.1*). This also means that there are some areas on the world where the climate is unsuitable for tourist activities. The most tourist activity has climatic constraints or limiting factors (as an example, the appropriate quantity and quality of snow are essential for ski-tourism). This implies that those areas where the terms of tourism activities are lacking have lower appeal. In such areas the tourism is more or less risky. This risk can be either financial or physical.

Secondly, the climate and weather can be also *dominating factor in tourist demand* (de Freitas, 2003; Matzarakis, 2006). The climatic conditions affect the tourists' decision on destination selection and mainly their time of travelling. However, the actual meteorological conditions influence the tourists what activities will be carried out in reality.

Finally, the climate and weather can be *risk factor for human health* because the trips in extreme climate areas may cause health problems (heat stroke, sunburn, asthma attack caused by air pollution, frostbite or other cold-related injury, etc.) (Matzarakis, 2006).

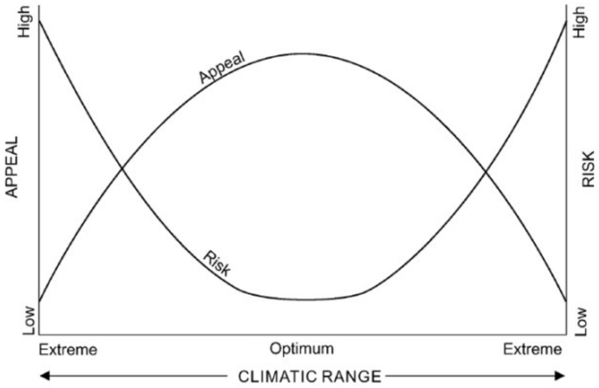


Fig. 1 Schematic representation of relationship between a climatic range and tourism potential. The climate potential of a particular location is a function of its climate and of the risks that weather may impose. (de Freitas, 2003 after Perry, 1997).

Tourism climate of a given area can be approached from several aspects. Some climate parameters are evaluated by physical (e.g. rain, air pollution), some by aesthetic or psychological (e.g. "clear blue sky"), while others by physiological (e.g. air temperature) aspect. One might think that the thermal component is the most important factor in terms of the tourism climate. But, if a region's temperature is in an acceptable range, the importance of the other factors increases in the tourism climatological evaluation. Let's examine some of these factors.

Physical factors are those meteorological parameters which affect the tourists' satisfaction directly or indirectly. As an example, the occurrence of a heavy rainfall during holidays has a direct impact on tourists which causes inconvenience (e.g. getting clothes or luggage wet), or affect indirectly the level of satisfaction (e.g. poor quality photos can be made). Physical factors include wind, ice and snow, severe weather conditions, or even the UV-rays.

The *aesthetic* (or psychological) aspects influence especially the attractiveness of the region and the enjoyment of holiday. This category includes the visibility, the cloudy or sunny day determined by the synoptic situation, and the length of the day.

The *thermal* aspects play role on the characterization of thermal comfort during the holidays. This means not only the air temperature, but the combined effect of temperature, humidity, solar radiation and wind.

The tourism climatology aims to examine and clearly demonstrate the above-mentioned characteristics for both tourists and tourism operators. Determining the tourism climate, simple climatic or bioclimatic indices were formerly used. Nowadays, more than 200 such indices exist. According to Matzarakis (2006), the tourism climatic indices can be divided into three categories. For calculating the *elementary indices,* one or more meteorological data are needed which do not contain any thermo-physiological information thus they do not really work in practice. The *bioclimatic* and *combined indices* include several climatic and bioclimatic parameters and their combined effect is taken into consideration. Some examples of the tourism climatic indices are shown in Table 1.

Table 1 Examples of tourism climate indices (after Matzarakis, 2006)

Category	**Parameters included**
Elementary	Air temperature, sunshine duration, precipitation
Bioclimatic	Windchill (air temperature and wind speed) Bioclimatic indices (based on human energy balance) – e.g. Predicted Mean Vote (PMV)*, Standard Effective Temperature (SET)*, Physiologically Equivalent Temperature (PET)*
Combined	Combination of parameters: daytime comfort index**, daily comfort index**, precipitation, sunshine duration, wind speed, PMV, PET

* definitions of these bioclimatic indices are in Fanger (1970), Gagge et al. (1986), Mayer and Höppe (1987)
** for definitions of these indices see Section "Tourism Climatic Index"

MATERIALS AND METHODS

Used data

In this study the measured meteorological data of the Storm Warning Observatory in Siófok (46°54'N, 18°02'E, 108 m asl) were used (*Fig. 2*). The measurements take place at the same location since the 1950's, so the data series do not have displacement-caused inhomogenity. This is particularly important for analyzing the long-term data series. The meteorological station is located right at the lakeside, thus it is ideal for tourism climatology. In the calculations the following measured data (for period 1961–2010) were utilized: hourly air temperature, relative humidity, vapour-pressure, wind speed, cloudiness; daily precipitation sum, average sunshine duration and daily maximum of wind speed.

Applied methods

1) Tourism Climatic Index (TCI)

There are several ways to determine the extent of the suitability of an area for tourism purpose in a climatic point of view. Several attempts have been made to identify the best or the optimal climate conditions for a tourism activity. Two of such methods were utilized in the present study.

First, one of the best-known and most widely used combined indices, the Tourism Climatic Index (TCI) was used. The TCI is favoured as an index because it is one of the most comprehensive metrics, integrating all three facets of climate considered relevant for tourism (Perch-Nielsen et al., 2010). The TCI was originally devised by Mieczkowski (1985) to exactly evaluate the climatic variables which are the most relevant for the quality of tourism experience of the "average" tourist. This work is based on the previous researches on relation between climate classification

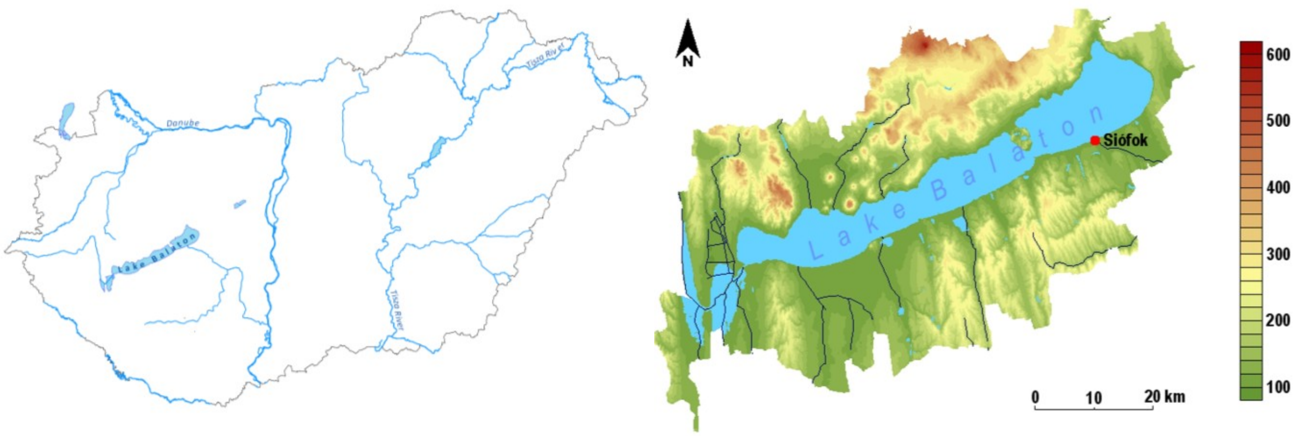


Fig. 2 Geographical location of the Lake Balaton Region in Hungary and the examined meteorological station (Siófok)

and recreation, and applied the human comfort-related outcomes too (Amelung and Moreno, 2012). The original index included 12 monthly climate variables. The final version of TCI was integrated only seven climatic variables (more precisely monthly averages of them): daily mean temperature, daily maximum temperature, daily mean relative humidity, daily minimum relative humidity, daily precipitation sum, daily sunshine duration and daily mean wind speed. These seven climatic variables were combined into five sub-indices (*Table 2*). A standardized rating (from the very bad of –3 to the very good of 10) system was devised to provide a common basis of measurement for each of the sub-indices.

In human biometeorological practice, many comfort indices exist for characterizing thermal comfort. Accordingly, the calculation of daily and daytime comfort index, which is included in the equation, can be done in several ways. The thermal comfort – in a subjective approach – is a kind of positive opinion (satisfaction), which expresses our relationship to the ambient thermal conditions. This subjective sensation is influenced basically by four meteorological factors: air temperature, relative humidity, wind speed and solar radiation. However, the *effective temperature (ET)* in its original form – which was applied by Mieczkowski (1985) for calculating the TCI – determines the combined effect only of the air temperature and air humidity (Hajek and Espinosa, 1982). ET is defined as the temperature of the saturated and stationary air mass which results the same total heat loss from the skin, and therefore the same thermal comfort sensation, as the actual environment. A serious problem with this definition of effective temperature is that it makes no special allowance for radiation.

The Tourism Climatic Index is calculated as follows:

$$TCI = 8 \cdot CID + 2 \cdot CIA + 4 \cdot P + 4 \cdot S + 2 \cdot W \qquad (1)$$

where:

CID = daytime comfort index
CIA = daily comfort index
P = precipitation
S = sunshine
W = wind speed

Based on a location's index value, its suitability for tourism activity is then rated on a scale from –30 to 100 (*Table 3*). Mieczkowski (1985) divided this scale into

Table 2 Sub-indices and their relative contribution to the TCI

Sub-index	**Climate variables**	**Influence on TCI**	**Weighting in TCI**
Daytime Comfort Index (CID)	maximum daily temperature and minimum daily relative humidity	Represents thermal comfort when maximum tourist activity occurs	40%
Daily Comfort Index (CIA)	mean daily temperature & mean daily relative humidity	Represents thermal comfort over the full 24-hour period, including sleeping hours too	10%
Precipitation (P)	daily precipitation sum	Reflects the negative impact that this element has on outdoor activities and holiday enjoyment	20%
Sunshine (S)	daily hours of sunshine duration	Acknowledged can be negative because of the risk of sunburn and added discomfort on hot days	20%
Wind (W)	daily averaged wind speed	Variable effect depending on temperature (evaporative cooling effect in hot climates rated positively, while 'wind chill' in cold climates rated negatively)	10%

ten categories, ranging from "ideal" (90 to 100), "excellent" (80 to 89) and "very good" (70 to 79) to "extremely unfavourable" (10–19) and "impossible" (–30 to 9). In this study, a TCI value of 70 or higher is considered attractive for the "typical" tourist engaged in relatively light activities such as sight-seeing and shopping.

Table 3 Tourism Climatic Index rating system (Mieczkowski 1985)

Numeric value of TCI	Description of comfort level for tourism activity
90 – 100	Ideal
80 – 89	Excellent
70 – 79	Very good
60 – 69	Good
50 – 59	Acceptable
40 – 49	Marginal
30 – 39	Unfavourable
20 – 29	Very unfavourable
10 – 19	Extremely unfavourable
Below 9	Impossible

2) Climate-Tourism-Information-Scheme (CTIS)

Although the Mieczkowski's TCI distributed worldwide as a tourism climate index, it has numerous limiting factors while using it. The most serious limitation of the TCI is its subjectivity and lack of verification (Perch-Nielsen et al., 2010). The effective temperature which is used to determine the daily and daytime comfort index is an outdated bioclimatic index. On the other hand, the TCI gives information about tourism climate in very poor temporal resolution. Therefore it has become necessary to develop a system, which can characterize a region's tourism climate in fine temporal resolution by using a modern, energy balance-based bioclimatic index.

One of the latest possibilities for the integration of climate/bioclimate information for tourism purposes is the Climate-Tourism-Information-Scheme (Matzarakis, 2007; Zaninović and Matzarakis, 2009). It represents frequencies and probabilities of different bioclimatic and tourism climatic factors from all facets. This method is particularly suitable for the analysis of selected destinations and therefore the tourist practice – policy makers and planners – in high spatial and temporal resolution climate information. Therefore the CTIS is not a tourism climatic index. Actually, the CTIS is a graphical representation of the tourism-relevant climatic information in high temporal resolution of 10 days – each month is divided into three time intervals (Matzarakis et al., 2012). The advantage of 10-day intervals is that it is roughly equal to the average duration of vacation time. Meanwhile the CTIS is a flexible system. In this case, the flexibility means that it can be selected one by one those climatic parameters which are relevant for a specific tourism sector in a specific region. For tourism in Lake Balaton Region the next CTIS factors are selected: cold stress (physiologically equivalent temperature i.e. PET<0°C), heat stress (PET>35°C), thermal comfort (18°C<PET<29°C), sunshine/cloud cover conditions in terms of the number of days with a cloud cover < 5 octas, vapour pressure > 18 hPa, relative humidity > 93%, precipitation < 1 mm as well as precipitation > 5 mm, and wind speed > 8 ms^{-1} as well as wind speed > 17 ms^{-1}. In general, the definitions of the several threshold values do not necessarily correspond to the universal meteorological threshold values and are adjusted to applied tourism climatology and human health applications.

For the calculation of the thermal component of CTIS, the Physiologically Equivalent Temperature (PET) was used. It is one of the most common bioclimate indices, which is derived from the Munich Energy-balance Model for Individuals (MEMI) (Höppe, 1984, 1999). The MEMI models the thermal conditions of human body in a physiologically way. Beside of meteorological parameters (air temperature, relative humidity, wind speed and cloudiness) some physiological and geographical inputs are required for calculating PET. For the calculation the RayMan software was used (Matzarakis et al., 1999, 2007). The calculation was taken on a 35 years old, 75 kg weight and 175 cm high man, who is sitting and wears normal clothing (0.9 clo). The categories of PET values were defined according to different thermal perceptions for temperate climate (*Table 4*).

Table 4 Categories of Physiologically Equivalent Temperature (PET) for different levels of physiological stress and thermal sensation (Matzarakis and Mayer, 1996)

PET (°C)	Grade of physiological stress	Thermal sensation
above 41	extreme heat stress	very hot
35 to 41	strong heat stress	hot
29 to 35	moderate heat stress	warm
23 to 29	slight heat stress	slightly warm
18 to 23	no thermal stress	comfortable
13 to 18	slight cold stress	slightly cool
8 to 13	moderate cold stress	cool
4 to 8	strong cold stress	cold
below 4	extreme cold stress	very cold

RESULTS AND DISCUSSION

Fig. 3 shows the monthly values of TCI for three climatological normal periods (1961–1990, 1971–2000 and 1981–2010) in Siófok. The many-years averages of TCI were 60.5, 61.5 and 61.8 in the three examined periods. Based on this, the region's tourism climate potential is good. The diagrams show clearly, that the tourism climate of the Lake Balaton has a summer peak. The high-

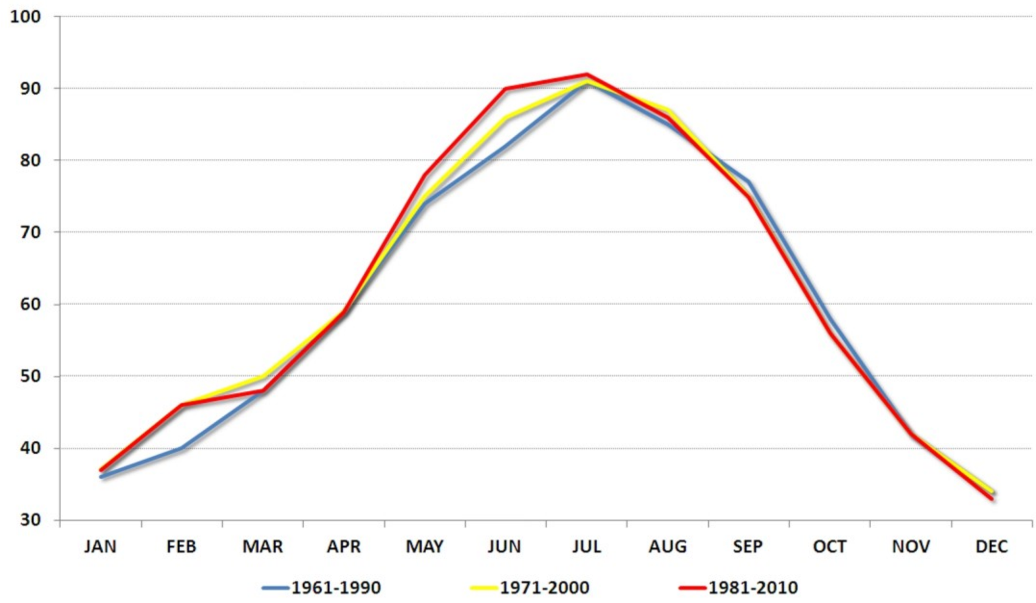


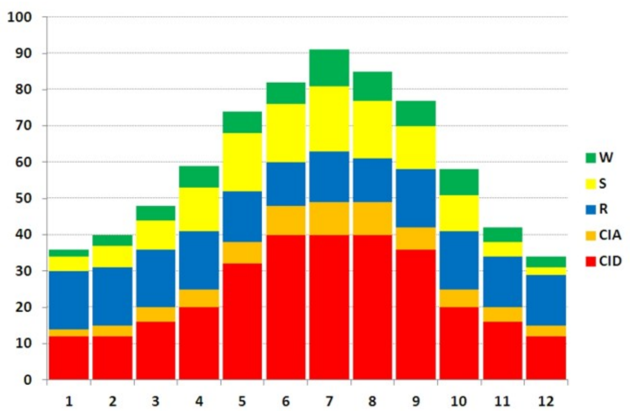
Fig. 3 The 30-year averages of the monthly means of Mieczkowski's Tourism Climatic Index in Siófok

est values (TCI ≥ 80) occur during the summer months, but altogether, the period from "good" to "ideal" lasts from May to September. The climatic requirements of tourism are not appropriate ("unfavourable") only in two months (December and January), but the TCI values do not go below 30 in these months.

Examining each climate periods it can be concluded, that there was no significant change in the climatic terms of the tourism in the last half-century in the studied region. The averages of TCI increased significantly only in February and June. The latter means the prolongation of the bath season in summer.

The change of TCI can be examined in more detail by analyzing the changes of sub-indices. Significant differences could not be explored between the two 30-year periods with 20-year difference by examining *Fig. 4*. However, some small characteristics can be observed. In February, the more favourable daytime comfort and precipitation conditions cause higher values of the TCI. This change in climate comfort can also be observed in May. In June, however, especially the aesthetic and physical components of the tourism climate changed favourably. The greatest change occurs in the wind conditions – this sub-index increased by 4 points.

Based on the CTIS diagrams (*Fig.* 5 and *Fig. 6*), from a thermal point of view, the favourable period (when the PET value is between 18 and 29°C) lasts from early May until the first third of October. Interesting that in contrast to the TCI graphs, we can talk about two-peak tourism season based on CTIS. The highest frequency of thermal comfort occurs in the end of May and in the middle of September. The rate of the comfort periods decreases temporarily during the summer months; this ratio is close to 30% in late July and early August. Heat stress (PET>35°C) should be expected typically in the summer months. The warmest period lasts from middle of July until beginning of August, when the highest frequency of heat stress occurs. Although, it should be noted, that the bathing potential of the area offset or makes it easier to endure these circumstances. The cold-stressed periods are frequent between mid-December and the end of January. The sultriness which is an important parameter in the thermal aspect reaches its maximum in early August, when the probability of these weather conditions is 50–60%. Comparing the period of 1961–1990 and



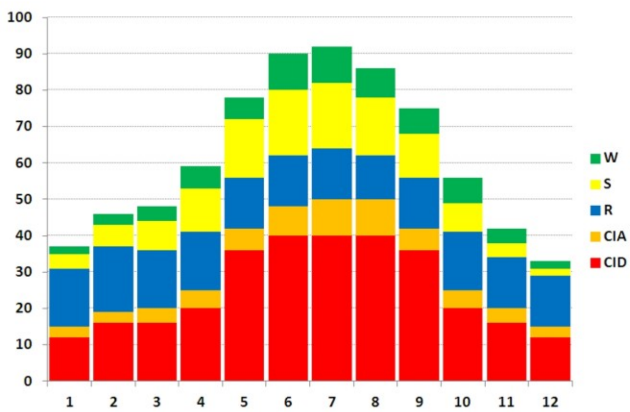


Fig. 4 The 30-year averages of the monthly means of sub-indices of TCI in Siófok for the period of 1961–1990 (left) and 1981–2010 (right)

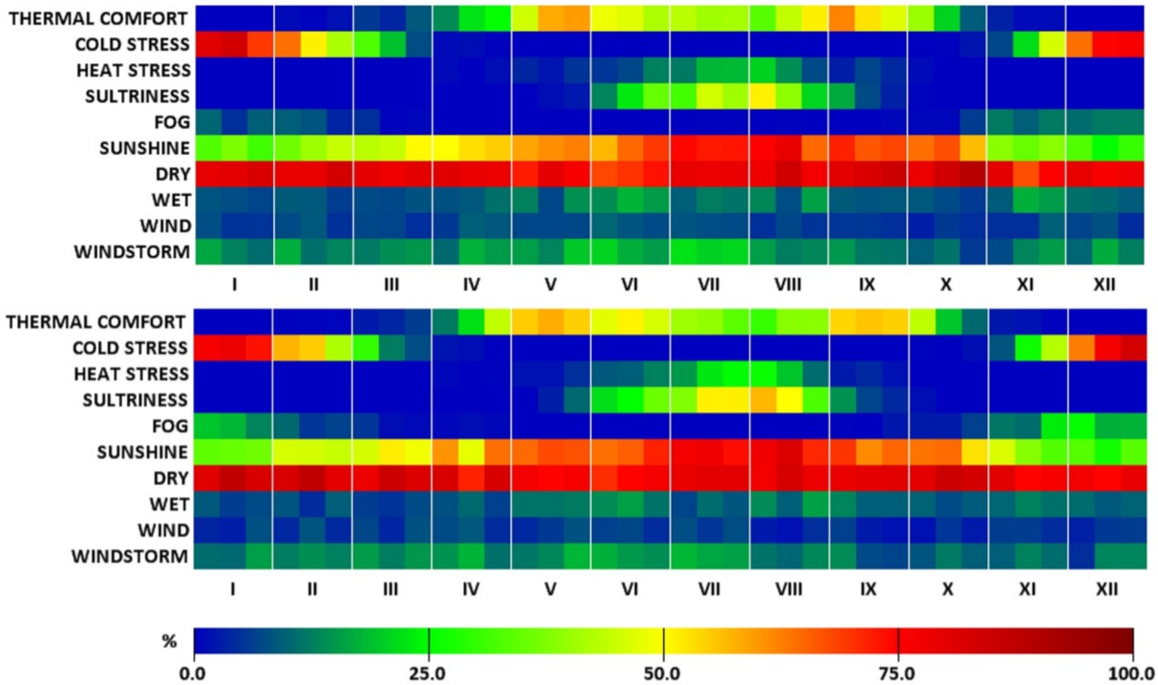


Fig. 5 CTIS (percent-type) in Siófok for the period of 1961–1990 (upper) and 1981–2010 (lower)

1981–2010, the above mentioned characteristics have become stronger, but the length of the tourism season did not change significantly.

The frequency of sunny days (according to the criteria) is favourable in terms of waterside tourism. Its ratio is above 50% during the period from April to October, but in July and August this ratio is close to 70–80%. Foggy weather can be expected from September to April, but its relative frequency of more than 20% is only in December and the first half of January. Examining the two 30-year periods, significant change can be seen especially in sunny days. The period of the sunny days increased in all seasons except in winter. This indicates the positive changes in the aesthetic component of the region's tourism climate.

The physical factors influence the region's tourism climate in a positive direction as a general rule. The precipitation and wind do not worsen the comfort sensation of the tourists. In this regard, there is no significant change between the two climate normal periods. The CTIS diagrams confirm the empirical fact that the climate of Lake Balaton is appropriate for lakeside tourism and other outdoor activities in the warmer half of the year.

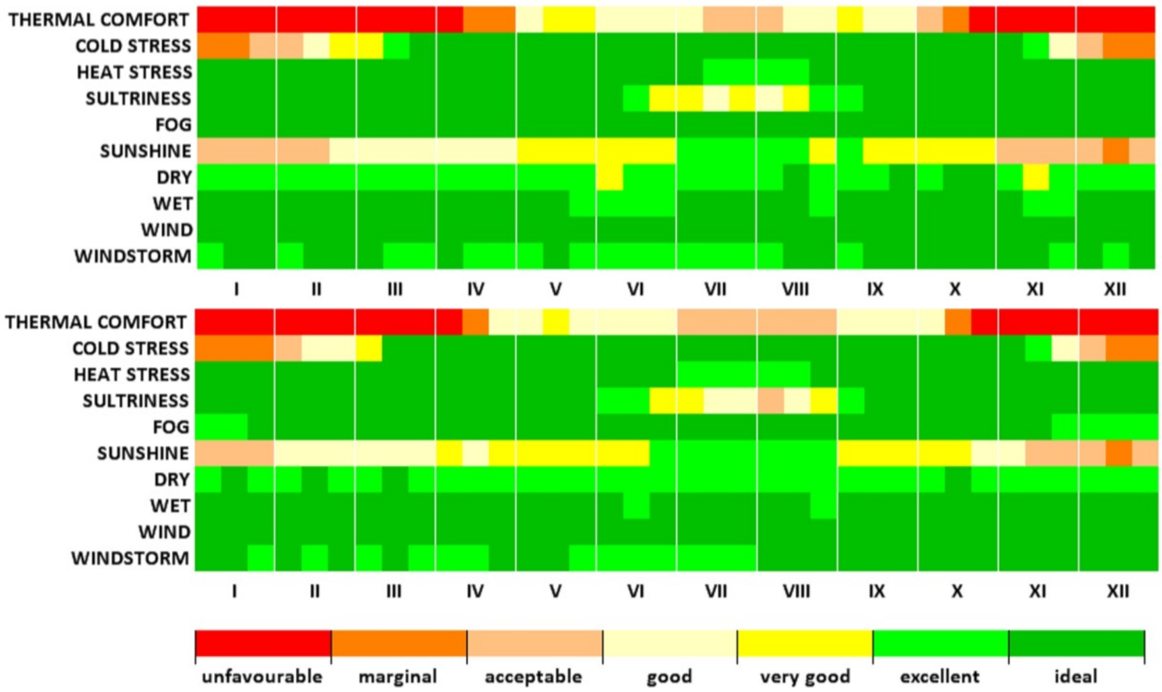


Fig. 6 CTIS (assessment-type) in Siófok for the period of 1961–1990 (upper) and 1981–2010 (lower)

CONCLUSIONS

Tourism climate is generally described by air temperature, precipitation and sunshine duration. Although these parameters are important, they do not describe the tourism climate potential of an area appropriately. Therefore, the tourism purpose examinations necessary to use such integrated indices or rating systems which take into account all the components of the tourism climate (physical, aesthetic and thermal). This paper means a step forward in this regard, because tourism climatological analyses with similar approach are not made previously. The results presented here can be easily interpreted for the travelling public and tourism operators.

The Mieczkowski's TCI index shows that the Lake Balaton Region's climate potential is favourable. The region has a positive climate for the lakeside tourism and other outdoor activities, especially in summer. The observed changes are insignificant over the past half-century; the climate potential only hardly changed. However this does not means that the future changes in the climate does not may cause a marked changes in the region's tourism climate. These analyses have to be carried out towards sustainable tourism development. Recent studies have shown that the region's climate supports only slightly the possibility of extending the tourist season.

Although the TCI is primarily developed for the analysis of urban tourism, it can be used almost in all sectors of the tourism industry. The TCI can be widely used because easy to calculate and does not require specific input data. In the future, however it would be advisable to examine that instead of the thermal comfort index (effective temperature), which is used in TCI, can be applied to other, modern bioclimatic index based on human energy balance (eg. physiologically equivalent temperature).

Based on CTIS, the region's tourism climate potential pattern is slightly different, it is rather bimodal. This is probably due to the CTIS factors were selected accordingly the tourism of this region (beach or lakeside tourism). Over the past 50 years, changes were appeared in the thermal and aesthetic (sunshine duration) components. In summer, the change in heat stress and sultriness may affect negatively to the tourism in the region. At the same time, the increase in sunshine duration assists to the beach tourism. On the whole, the tourism climate potential of Lake Balaton Region rose slightly over the past 50 years due to the changing climate.

Comparing the classic TCI with the CTIS, it should be highlighted the better temporal resolution and a more detailed criteria-system of the CTIS. The 10-days resolution of CTIS is near to the average length of stay of visitors.

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